The elements of natural or experimental philosophy

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THE

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OF

NATURAL OR EXPERIMENTAL

PHILOSOPHY.

BY TIBERIUS CAVALLO, F.R.S. &c.

ILLUSTRATED WITH COPPER PLATES.

IN FOUR VOLUMES.

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ELEMENTS OF

NATURAL PHILOSOPHY.

PART III.

OUR knowledge of the various conſtituent principles of natural bodies, goes no farther than their more ſtriking effects. The ſimilarity of ſome of thoſe effects, and the diſſimilarity of others, point out various particular properties of thoſe principles, whence we are enabled to form certain general rules, called laws of nature. Therefore it follows, that with reſpect to the eſſential or ſimple ſtate of thoſe principles, we can only form conjectures, or offer hypotheſes; yet the more circumſcribed nature of ſome of them, renders our hypothetical knowledge of their eſſence more probable, and leſs equivocal, than that of other principles.

Four of the latter ſort have, on account of their wonderful effects, and of their very extenſive influence, been ſet apart for a more particular examination. Theſe are *caloric*, *light*, *electricity*, and *magnetiſm*.

magnetiſm. The principal properties of thoſe natural agents, the more probable opinions which have been entertained with reſpect to their eſſence, and the principal advantages which we derive therefrom, will form the contents of the preſent, or third, part of theſe Elements; which, therefore, will be divided into four ſections; and each ſection will be ſubdivided into as many chapters as the nature of the ſubject may ſeem to demand, conſiſtent with perſpicuity and conciſeneſs.

SECTION I.

OF CALORIC; OR, OF THE ELEMENT WHICH PRODUCES HEAT, FIRE, &C.

A GENERAL idea of the element which produces the ſenſation of heat, &c. has been given in the preceding volume, wherein the nature of the affinities of the various elements has been conciſely illuſtrated. In the following pages we muſt unavoidably repeat ſome of the particulars which have been already mentioned; but the repetition will be ſhort, and the advantage, in point of perſpicuity, will probably prove more than an adequate compenſation for the trouble of twice peruſing a few paſſages.

CHAPTER I.

THE THEORY OF HEAT; OR, THE GENERAL EFFECTS OF A SUPPOSED CALORIFIC FLUID.

WHEN we approach a common fire, we feel a ſenſation which we call *heating*. When we recede from the fire, and approach a quantity of ice, we feel another ſenſation, which we call *cooling*. On a cloſer examination it will appear that theſe words *heating* and *cooling*, or *heat* and *cold*, are relative expreſſions; for the very ſame body may feel cold to one perſon and hot to another; or it may feel both cold and hot to the ſame perſon. Let, for inſtance, a perſon warm one of his hands near the fire, and cool the other hand in ſnow; then let him put both hands in water of a middling temperature, and the ſame water will feel cold to one of his hands, and hot to the other.

It is impoſſible to give a more preciſe definition of thoſe ſenſations, than what is conveyed by the common meaning of the words. But with reſpect to the viſible effects which are produced by thoſe reſpective approximations, to a fire and to the ice, or to the different degrees of heating and cooling, we we may give a more determinate anſwer; viz. we may ſay, that all the effects of heating may be reduced to an enlargement of the bulk, or to the ſeparation of the parts, of all ſorts of bodies; and that, on the contrary, all the effects of cooling may be reduced to a contraction of the bulk, or to a mutual approximation, of the parts, of all ſorts of bodies.

A human body, and every part of an animal body, a ſtone, a piece of metal, a piece of glaſs, or, in ſhort, every other body, whether ſolid or fluid, grows larger by heating, and ſmaller by cooling; but different bodies are expanded more or leſs by the ſame degrees of heating, and are contracted more or leſs by the ſame degrees of cooling. Bodies are not only expanded differently by the ſame degrees of heating, or contracted differently by the ſame degrees of cooling; but by thoſe means they do alſo acquire different forms. Thus a piece of ice heated to a certain degree, becomes fluid water; by increaſing the heat the water is increaſed in its bulk, and after a certain period the water becomes an elaſtic fluid; viz. ſteam. By continuing to increaſe the heat, that ſteam becomes continually larger and larger; nor do we know the limits of its expanſibility. The like effects, in a contrary order, are produced by cooling; viz. a quantity of ſteam grows ſmaller and ſmaller, until it becomes liquid water, and at laſt the water becomes a ſolid; viz. *ice*.

The converſe of the above-mentioned law has likewiſe been pretty well proved by means of experiments; namely, that if a certain ſubſtance be compreſſed into a narrower ſpace, a quantity of heat will come out of it, and will be communicated to the ſurrounding bodies; and, on the contrary, if a certain ſubſtance be expanded into a larger ſpace, it will abſorb a quantity of heat from the ſurrounding bodies; for thoſe ſurrounding bodies will thereby be cooled. Thus, if you wet your hand, and then expoſe it to the ambient air, the water, in the act of expanding itſelf into vapour, abſorbs a quantity of heat from the hand, which is thereby ſenſibly cooled. If air that has been compreſſed by art in a ſtrong veſſel, be let out of it through an aperture, that air, in the act of expanding itſelf, will abſorb a quantity of heat. If a piece of metal be compreſſed, heat will be produced. If the ſteam of water be condenſed, heat will be depoſited on the bodies which are in contact with it.

The acceſſion of heat, by placing the particles of matter farther from each other, diminiſhes their mutual attraction; viz. the attraction of aggregation, in conſequence of which their attraction for other bodies; viz. the attraction of affinity, grows ſtronger; hence, heating to a certain degree effects decompoſitions and compoſitions, which in general have been called *combuſtions*; but when the heated ſubſtances have not ſuch affinities, or when they are not heated enough to render their affinities active, ſo as to form decompoſitions and new combinations, then the ſubſtances are not ſaid to have undergone a combuſtion, or to be burnt; but they are ſaid to be heated, or rarefied, or ignited; (viz. rendered red hot) or ſoftened, or liquified, or evaporized, &c. according as any of thoſe effects is produced or attended to.

Heat penetrates bodies of every ſort; for whatever body is placed near a common fire, is expanded, or ſoftened, or ignited; or, in ſhort, it ſhews ſome of the effects of heating; and the ſame thing is true with reſpect to cooling; but this heating does not penetrate all ſorts of bodies with equal quickneſs; it paſſes through certain bodies quicker or eaſier, than through others; hence the former are ſaid to be *better conductors of heat*, than the latter; we are not however acquainted with any body which may be ſaid to be a perfect nonconductor of heat.—The ſame thing may be underſtood of cooling.

With reſpect to the communication of heat, it has been obſerved, that if an heated body be placed amongſt colder bodies, or heat be produced by certain bodies in certain proceſſes amongſt colder bodies, that heat will gradually paſs from the former bodies to the latter, ſo as to render the former bodies leſs hot, and the latter, hotter, than they were before; and as there is not a perfect nonconductor of heat, therefore nothing can effectually

fectually prevent that expanſion, or that diſtribution, of heat; though it may be much obſtructed and impeded by the interpoſition of bad conducting bodies.

So far the effect is well known, and is daily proved by common experience. But there is another phenomenon attending the communication of heat, which is neither very obvious, nor ſo eaſily obſerved. This is, that in the diſtribution of heat amongſt a variety of ſubſtances, ſome bodies abſorb more of it than others, though they be all placed exactly in the ſame ſituation; hence different bodies are ſaid to have different *capacities* for abſorbing heat.—An example will eaſily illuſtrate this remarkable property.

If a pound of water heated to a certain degree, for inſtance, to 60 degrees, be mixed with another pound of water which has been heated 120 degrees, the 60 degrees of heat, which the latter has above the former, will be divided alike between thoſe equal quantities of water; viz. 30 degrees will be communicated to the former pound of water, and the other 30 degrees of heat will remain with the latter; hence the whole will appear to have 90 degrees of heat. Now, if a pound of water heated to 60 degrees, be mixed with a pound of quickſilver, heated to 120 degrees, the mixture will appear to have (not 90 degrees as above) but only 62 degrees of heat; which ſhews, that of the 60 degrees of heat, which the mercury had more than

than the water, a greater portion muſt have been abſorbed by one of the two fluids than by the other. In order to aſcertain which of the two has abſorbed the greateſt quantity of heat, you need only repeat the experiment with this difference; viz. that the pound of water be heated to 120 degrees, and the pound of mercury be heated to 60 degrees; for in this caſe the mixture will appear to have the heat of 118 degrees; which plainly ſhews, upon the leaſt reflection, that the water has a much greater capacity for abſorbing heat, than the quickſilver.

The above-mentioned particulars are the heads to which all the phenomena of heating and cooling may be referred; and ſo far we have related facts: but if the cauſe of thoſe facts be demanded, we muſt then anſwer by means of ſuppoſitions or hypotheſes.

Various hypotheſes have at different times been offered by different philoſophers in explanation of this ſubject; but of all thoſe hypotheſes, none ſeems to be ſo ſatisfactory as the modern theory of heat, which is as follows:

1ſt. It is ſuppoſed that there exiſts a very ſubtile and elaſtic fluid, diſperſed throughout all the bodies of the univerſe, and capable of paſſing, with more or leſs facility, through them all: but this fluid cannot be exhibited by itſelf in an uncombined ſtate; for nothing will confine it; nor has it any known weight.

2dly. Dif-

2dly. Different bodies have different affinities for this fluid, or they can abſorb different quantities of it, juſt as pieces of different woods can abſorb different quantities of water; and thoſe affinities are increaſed or diminiſhed by a variety of cauſes, ſuch as by combination with other ſubſtances, by compreſſion, by expanſion, &c. hence this fluid, owing to the conſtant action of thoſe cauſes in the world, is continually moving from one ſet of bodies to another.—Its tranſition, its accumulation on one body, and its diminution on another body, give motion to every particle of matter, and ſeem to animate the whole; for every body is rarefied and condenſed by the accumulation or diminution of this fluid. And every body is ſuſceptible of different ſtates by its combination with a greater or ſmaller quantity of this fluid. Thus ice is a combination of ſolid water with a certain quantity of this element; fluid water is combined with a greater quantity of it; and vapour is a combination of water with a much greater quantity of this element.

3dly. This ſuppoſed, ſubtile, and elaſtic, fluid, has been called *elementary heat*, or, ſimply, the *caloric*.

According to this hypotheſis, *combined caloric* is that quantity of caloric which enters into combination with other bodies, and which quantity has been ſaid to differ according to the nature of each particular body. Thus in the above-mentioned inſtance

ſtance of a mixture of water and mercury, the water has been ſhewn to contain more combined caloric than the mercury. *Free caloric* is that portion of it which is not combined with a certain body, but which is ready to paſs from that body to other ſurrounding bodies; and the quantity of it, (which is meaſured by the effect it produces on thoſe other bodies; viz. by the quantity of expanſion, &c.) is called the *temperature* of that body. The ſenſation which animals perceive by the communication of caloric to their bodies, is called *heat*, or *heating*; and the ſenſation which they perceive by the eſcape of the caloric from their bodies, is called *cold*, or *cooling*. Therefore it appears, that *cold* is not a poſitive thing; for it is only the abſence or privation of caloric. When we touch a hot body, the caloric paſſes from that body into our hand, or face, &c. expands that part, and excites in us a ſenſation of heat. When we touch a cold body, the caloric paſſes from us to that body, and we feel the ſenſation of cold. By a cold or hot body, it is meant only that a body is colder or hotter than our bodies, or a certain other body; ſo that when our body touches a body of the ſame temperature, then we feel neither heat nor cold, becauſe in that caſe there is no tranſition of caloric either way.

Thus we have briefly ſtated a ſummary of the phenomena which fall under the common appellations of heat and cold, and have ſubjoined the moſt plauſible hypotheſis, which has been offered for their explanation. But it is now neceſſary to examine the different parts of the ſubject in a manner both more particular and more uſeful; viz. to ſtate the facts which have been aſcertained with reſpect to the expanſion of different bodies, with reſpect to the meaſurements of that expanſion, with reſpect to the different capacities of bodies for abſorbing caloric; as alſo the facts relative to the production, communication, and application of heat, &c.—This we ſhall endeavour to do in the following chapters, wherein we ſhall add the theoretical explanation, agreeably to the above-mentioned hypotheſis.

CHAPTER II.

OF THE THERMOMETER; AND OF THE DILATATION OF BODIES, WHICH IS PRODUCED BY HEAT.

ONE of the moſt general effects of heat, or of the free caloric, is a dilatation of bodies, or an augmentation of their bulks. The contrary effect is produced by cold; viz. by a diminution of the free caloric. It muſt, however, be obſerved, that bodies of equal bulks, but of different kind, are not expanded alike by being heated to the ſame degree; nor are the increments of bulk in the ſame body, always proportional to the quantities of heat which are communicated to it.—If a bar of iron and a bar of glaſs, of equal dimenſions, be both heated to the ſame degree. for inſtance, by plunging them in boiling water, the bar of iron will thereby be lengthened more than that of glaſs. —If a given quantity of water, by being heated to a certain degree, be increaſed in bulk one cubic inch, the addition of double or treble that quantity of heat will not increaſe its bulk two or three cubic inches reſpectively; therefore, the expanſions of water

water are not proportional to the increments of heat.—This is alſo the caſe with moſt other ſubſtances.

We muſt now ſtate the moſt remarkable facts which have been aſcertained reſpecting the dilatation of particular ſubſtances, fluid firſt, and then ſolid.

The only practicable method of meaſuring the expanſions of fluids, is by incloſing them in certain veſſels, and by meaſuring that part of the cavity of each veſſel which is occupied by the particular fluid which fills it in different temperatures. It is evident that the ſubſtance of the veſſel is alſo expanded by the heat, and of courſe its cavity is enlarged. Therefore, when we find that the bulk of the fluid is increaſed, that apparent increment is only the difference between the enlarged capacity of the veſſel and the increaſed bulk of the fluid. For this reaſon thoſe veſſels muſt be made of ſuch ſubſtances as are leaſt expanſible by heat. Indeed glaſs is the ſubſtance which is univerſally uſed for ſuch purpoſes, both on account of its little expanſibility, and of its tranſparency, beſides its having other remarkably uſeful properties.

A glaſs veſſel filled to a certain degree with a liquid, for the purpoſe of ſhewing the expanſions of that liquid in different temperatures, or for the purpoſe of ſhewing the temperature by the correſponding expanſion of that liquid, is called a *thermometer*; viz. a meaſurer of the temperature.

The

The fluids moſtly uſed for thermometers, are either mercury or ſpirit of wine, the latter of which is generally tinged red, by means of cochineal, or Brazil wood, &c. for the purpoſe of rendering it more viſible; hence they are denominated the *mercurial thermometer*, and the *ſpirit thermometer*. Other fluids, on account of their clammineſs, or of their great irregularity of expanſion, are not uſeful for thermometers [*].

The moſt proper and the moſt uſeful ſhape for thermometers, is that of a long tube with a narrow bore, and with a globular cavity at one extremity. See fig. 1. of Plate XVIII. The cavity of the bulb C, and part of the tube, as far, for inſtance, as A, is filled with the fluid, the reſt of the tube is either partly, or quite, exhauſted of air, and the end B of the tube is hermetrically ſealed; viz. perfectly cloſed by melting the extremity of the tube at the flame of a candle or lamp, urged by means of a blow-pipe [†].

When

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[*] Thermometers have alſo been made with bars of metal, without any glaſs or fluid. Theſe ſhew the temperature by the expanſion of the bars, and are, therefore, called *metallic thermometers*.—They will be noticed hereafter.

[†] On account of the narrowneſs of their bore, it is impoſſible to fill thermometers merely by pouring the fluid into their cavity. But in order to fill a thermometer, the bulb

When the bulb C is heated, the mercury, or the ſpirit of wine is expanded; and not being able to extend itſelf any other way, all the increment of bulk is manifeſted in the tube; viz. the ſurface A of the fluid will riſe conſiderably into the tube. On the other hand, when the bulb C is cooled, the fluid contracts, and its ſurface A deſcends. It is evident, that, *cæteris paribus*, the larger the bulb is, in proportion to the diameter of the cavity of the tube, or the narrower the latter is in proportion to the former, the greater will the motion of the ſurface

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bulb C muſt be heated over the flame of a candle, and, immediately after, the aperture B muſt be turned downwards, and muſt be immerſed in the fluid; for inſtance, the mercury; by which means part of the bulb will be filled with mercury; for the heat of the candle having rarefied, and of courſe expelled ſome of the air from the cavity of the thermometer, when afterwards the bulb cools, and the air in it is condenſed, the atmoſphere preſſing upon the ſurface of the mercury in the baſon, forces it into the tube and bulb. This done, the bulb C is again heated over the flame of the candle, until the mercury in it appears to boil, and is then immediately turned down, with the aperture B, into the mercury; by which means more mercury will be forced into the bulb. This operation muſt be repeated until all the air is removed from the bulb, and part of the tube, and its place is occupied by the mercury. When this is done, heat the bulb gently, ſo as to rarefy the mercury, and to elevate its ſurface very near the aperture B; and, in that ſtate, quickly ſeal the aperture B by means of the blowpipe.

ſace A be in the tube. But it muſt be obſerved, that when the bulb is very large, the thermometer will not eaſily arrive at the preciſe temperature of any place, wherein it may be ſituated. Some perſons, in order to give the bulb a greater ſurface, and of courſe to render it more capable of readily attaining a given temperature, have made it not globular, but cylindrical, (which ſhape was adopted by Fahrenheit) or flat, or bell-like, &c.; but thoſe ſhapes are improper, becauſe they are liable to be altered by the varying gravity of the atmoſphere, conſequently thoſe thermometers cannot be accurate.

If a thermometer be heated ſuddenly, as when the bulb C is immerged in hot water, the ſurface A of the fluid in it will be ſeen to deſcend a little, and inſtantly after will be ſeen to riſe; the reaſon of which is, that the heat of the water enlarges the glaſs firſt, and is then communicated to the fluid, &c. On the contrary, if the bulb of a thermometer be cooled ſuddenly, the ſurface A of the fluid will firſt riſe a little, and then will deſcend; becauſe the cold contracts the glaſs alone at firſt, and does afterwards contract the fluid.

Ice is melted by a certain invariable degree of temperature; and water freezes at about the ſame temperature; therefore, if the bulb C of a mercurial thermometer be placed in melting ice, or melting ſnow, and a mark is made on the outſide of the tube, even with the ſurface of the fluid, as at D;

that mark is called the *freezing point*, though in fact it is the melting point of ice; the freezing point of water being not ſo conſtant. If the bulb of the thermometer be placed in boiling water, and a mark be made on the glaſs tube, even with the ſurface of the fluid within, as at E, that mark is called the *boiling point*; for in an open veſſel, and under the ſame atmoſpherical preſſure, which is indicated by the barometer, water does conſtantly boil at the ſame temperature, and an increaſed fire will force it to evaporate faſter, but will not raiſe its temperature. Thoſe points being aſcertained, if the length of the tube from D to E be divided into any number of equal parts, thoſe parts will be the degrees of the thermometer, or the degrees of heat, indicated by the correſponding expanſions of the fluid within the thermometer. And the ſame degrees, or equal diviſions, may be continued below D and above E, in order to ſhew the degrees of temperature below the freezing, and above the boiling, point *.

Thoſe two unalterable points of temperature; viz. the former where ice becomes water, and the ſecond where water becomes vapour, have been univerſally adopted by the various conſtructors of thermometers for the graduation of thoſe inſtru-

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* For a more accurate method of graduating thermometers, ſee the Report of the Committee, appointed by the Royal Society, in the 67th vol. of the Philoſophical Tranſactions, p. 816.

ments; but the ſpace between them has been divided differently by different perſons, and this difference gives the different names of thermometers, or rather of their graduations; ſuch as *Reaumur's thermometer*, *Fahrenheit's thermometer*, *&c.* Reaumur divides the ſpace between the abovementioned two points, into 80 equal parts or degrees; placing the 0 at freezing, and the 80th degree at the boiling point. Fahrenheit divides it into 180 degrees or equal parts, but he places the 0 thirty-two degrees below the freezing point D; ſo that the freezing point is at 32, and the boiling point E is at 212 degrees*.

Other perſons have adopted other diviſions, which have been ſuggeſted by ſuppoſed advantages or fanciful ideas.

Moſt of thoſe graduations are at preſent out of uſe; but they are to be met with in various, not very recent, publications; I have therefore thought neceſſary to ſet them down in the following Table, which contains; 1ſt, the name of the perſon or ſociety that has uſed each particular diviſion; 2dly, the degree which has been placed, by each of them, againſt the freezing point; 3dly, the degree which has been placed againſt the boiling point; and 4thly, the number of degrees laying between thoſe two points.

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* Inſtead of adding the word *degrees* to the number, a ſmall ° is annexed to it on the right-hand ſide, a little above the level of the number; thus 24°. means 24 *degrees*; 60°. means 60 *degrees*, &c.

	Freezing point.	Boiling point.	Degrees between the preceding two points.
Fahrenheit's, which is generally uſed in Great Britain. It is alſo uſed throughout this work, unleſs ſome other be mentioned - - - -	32	212	180
Reaumur's, which is generally uſed in France and other parts of the Continent - -	0	80	80
Celſius's, which has been uſed chiefly in Sweden, hence it is alſo called the Swediſh thermometer. It has been lately adopted by the French chemiſts, under the name of *centigrade thermometer* - - - - - -	0	100	100
The *Florentine Thermometers*, which were made and uſed by the members of the famous Academy *del'Cimento*, being ſome of the firſt inſtruments of the ſort, were vaguely graduated, ſome having a great many more degrees than others. But two of their moſt common graduations ſeem to be - -	20 13 $\frac{1}{2}$	174 81 $\frac{2}{3}$	154 68 $\frac{1}{6}$
The *Pariſian Thermometer*, viz. the *ancienne thermometre* of the Academy of Sciences, ſeems to have been graduated nearly thus - - - -	25	239	214

	Freezing point.	Boiling point.	Degrees between the preceding two points.
De la Hire's Thermometer, which ſtood in the Obſervatory at Paris above 60 years, ſeems to be graduated thus - -	28	199 $\frac{1}{3}$	171 $\frac{1}{3}$
Amonton's - - - - - -	51 $\frac{1}{2}$	73	21 $\frac{1}{2}$
Poleni's - - - - - - -	47 $\frac{3}{10}$	62 $\frac{9}{10}$	15 $\frac{6}{10}$
De l'Iſle's Thermometer is graduated in an inverted order	150	0	150
Crucquius's - - - - - -	1070	1510	440
The ancient Thermometer of the Royal Society of London, ſeems to have had the 0 correſponding with about the 88th degree of Fahrenheit's; and from that point the numeration aſcended and deſcended; viz. - -	73 $\frac{3}{4}$	141 $\frac{3}{4}$	215 $\frac{1}{2}$
Sir Iſaac Newton's - - -	0	34	34
Fowler's 0 ſeems to have coincided with about the 53d or 54th degree of Fahrenheit's, and from that point the numeration aſcended and deſcended, thus - - -	34	250 $\frac{1}{3}$	284 $\frac{1}{3}$
Hales's - - - - - - -	0	163	163
The *Edinburgh Thermometer*, formerly uſed *, ſeems to have been graduated thus	8 $\frac{1}{5}$	47	38 $\frac{4}{5}$

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* See Dr. G. Martine's Eſſays, Med. and Phil.

Thermometers

Thermometers have been made of a great variety of ſhapes and ſizes, ſuitable to the different purpoſes for which they were intended.

Thermometers for ſhewing the temperature of the atmoſphere, need not have their ſcales much extended; it is more than ſufficient if they go as high as 120°. The lower degrees may be carried down as low as may be ſuppoſed neceſſary for the cold of any particular climate. The mercurial thermometer needs not be graduated lower than 40° below 0, becauſe at about that degree mercury ceaſes to be a fluid.

The ſpirit thermometer may be graduated lower if neceſſary.—I ſhall here juſt mention, that, for reaſons which will be noticed hereafter, if a mercurial thermometer and a ſpirit thermometer, be both graduated according to the above-mentioned directions, the two thermometers will not, in their uſual indications of the ſame temperatures, point to the ſame degrees.

The degrees of thermometers may be delineated on metal, or wood, or paper, or ivory, &c. but ſuch ſubſtances ſhould be preferred for the ſcales of thermometers, as are not apt to be bent or ſhortened, or otherwiſe altered by the weather, eſpecially when the inſtruments are not defended by a glaſs caſe, or by a box with a glaſs face.

The bulb of the thermometer muſt be clean and colourleſs; ſince coloured ſurfaces are apt to be partially heated by a ſtrong light *. The ball of the thermometer ought not to be in contact with the ſubſtance of the ſcale, leſt it ſhould be influenced by the temperature of that ſubſtance.

Thoſe thermometers muſt be ſituated in the open air out of the houſe, and at ſome diſtance (at leaſt a foot) from the wall, and where the light of the ſun may not fall directly upon them. Fig. 2. Plate XVIII. repreſents a thermometer of the moſt uſual ſhape independent of the caſe.

For chemical purpoſes, the bulbs and part of the tubes of the thermometers, muſt project ſome way below the ſcales, in order that they may be placed in liquids, mixtures, &c.

For other purpoſes, as for botanical obſervations, hot houſes, brewing manufactories, baths, &c. the thermometers muſt be made longer, or ſhorter, or narrower, or particular directions muſt be added to the ſcales, &c.; but I ſhall not take any farther notice of thoſe fluctuating varieties of ſhape only.

It is neceſſary, however, to take notice of a ſort of thermometers which have been conſtructed for a particular purpoſe; namely, for ſhewing the

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* Take two equal thermometers, paint the bulb of one of them black, or of any dark colour, and expoſe them both to the ſun; the mercury in the latter will riſe ſeveral degrees higher than in the former. Even a ſtrong day light, independent of the direct rays of the ſun, will affect them differently.

higheſt degree of heat or of cold which has taken place during the abſence of the obſerver; as for inſtance, in the courſe of the night, or in the hotteſt part of the day, or even during a whole ſeaſon.

Thermometers for this purpoſe have been contrived differently by various ingenious perſons, as by Bernoulli, Kroft, Lord Charles Cavendiſh, &c.* but the beſt of them (which however is not without faults, and of courſe is in need of improvements) was contrived by Mr. James Six, and is deſcribed in the 72d vol. of the Philoſophical Tranſactions. Fig. 3. Plate XVIII. exhibits this inſtrument, but diveſted of the ſcale and frame; “ *a b* is a tube of thin “ glaſs, about 16 inches long, and $\frac{5}{16}$ of an inch in “ diameter; *c d e f g h*, a ſmaller tube with the “ inner diameter, about $\frac{1}{40}$, joined to the larger at “ the upper end *b*, and bent down, firſt on the “ left ſide, and then, after deſcending two inches “ below *ab*, upwards again on the right, in the ſe- “ veral directions *c d e*, *f g h*, parallel to, and one “ inch diſtant from it. On the end of the ſame “ tube at *h*, the inner diameter is enlarged to half “ an inch from *h* to *i*, which is two inches in “ length. This glaſs is filled with highly rectified

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* See Diff. *ſur la Comparaiſon du Therm. par Van Swinden*, p. 253--255. The Philoſophical Tranſactions, vol. L. and vol. LI. The Tranſactions of the Edinburgh Society; and the Encyclopædia Brit. article *Thermometer.*

" ſpirits of wine, to within half an inch of the end " *i*, excepting that part of the ſmall tube from *d* " to *g*, which is filled with mercury. From a view " of the inſtrument in this ſtate, it will readily be " conceived, that when the ſpirit in the large tube, " which is the bulb of the thermometer, is expanded " by heat, the mercury in the ſmall tube on the " left ſide will be preſſed down, and conſequently " cauſe that on the right ſide to riſe; on the contrary, when the ſpirit is condenſed by cold, the " reverſe will happen, the mercury on the left ſide " will riſe as that on the right ſide deſcends. The " ſcale, therefore, which is Fahrenheit's, beginning " with o, at the top of the left ſide, has the degrees " numbered downwards, while that at the right " ſide, beginning with o at the bottom, aſcends. " The diviſions are aſcertained, by placing this thermometer with a good ſtandard mercurial one in " water, gradually heating or cooling, and marking " the diviſions of the new ſcale at every 5°. The " method of ſhewing how high the mercury had " riſen in the obſerver's abſence, is effected in the " following manner. Within the ſmall tube of the " thermometer, above the ſurface of the mercury " on either ſide, immerſed in the ſpirit of wine, is " placed a ſmall index, ſo fitted as to paſs up and " down as occaſion may require: that ſurface of " the mercury which riſes, carries up the index " with it, which index does not return with the " mercury when it deſcends; but, by remaining " fixed,

“ fixed, ſhews diſtinctly, and very accurately, how
“ high the mercury had riſen, and conſequently
“ what degree of heat or cold had happened.
“ Fig. 4. Plate XVIII. repreſents theſe indexes
“ drawn larger than the real ones, to render it more
“ diſtinct; *a* is a ſmall glaſs tube $\frac{3}{4}$ of an inch long,
“ hermetically ſealed at each end, incloſing a piece
“ of ſteel wire, nearly of the ſame length; at each
“ end *c d*, is fixed a ſhort piece of a tube of black
“ glaſs, of ſuch a diameter as to paſs freely up and
“ down within the ſmall tube of the thermometer.
“ The lower end, floating on the ſurface of the
“ mercury, is carried up with it when it riſes,
“ while the piece at the upper end, being of the
“ ſame diameter, keeps the body of the index
“ parallel to the ſides of the thermometrical tube.
“ From the upper end of the body of the index at
“ o, is drawn a ſpring of glaſs to the fineneſs of a
“ hair about $\frac{5}{7}$ of an inch in length, which being ſet
“ a little oblique, preſſes lightly againſt the inner
“ ſurface of the tube, and prevents the index from
“ following the mercury when it deſcends, or being
“ moved by the ſpirit paſſing up or down, or by
“ any ſudden motion given to the inſtrument by the
“ hand or otherwiſe; but at the ſame time the
“ preſſure is ſo adjuſted, as to permit this index to
“ be readily carried up by the ſurface of the riſing
“ mercury, and downwards whenever the inſtrument
“ is to be rectified for obſervation. To pre-

“ vent

"vent the ſpirit from evaporating, the tube at the "end *i* is cloſely ſealed.

"This inſtrument in its frame muſt be ſecured "againſt the wall out of doors, to prevent its being ſhaken by violent winds. Towards evening "I uſually viſit my thermometer, and ſee at one "view, by the index on the left ſide, the cold of "the preceding night; and by that on the right, "the heat of the day. Theſe I minute down, and "then apply a ſmall magnet to that part of the tube "againſt which the indexes reſt, and move each of "them down to the ſurface of the mercury: thus, "without heating, cooling, ſeparating, or at all "diſturbing the mercury, or moving the inſtrument, may this thermometer, without a touch, be "immediately rectified for another obſervation."

It might at firſt ſight be imagined that equal increments of heat would cauſe fluids to expand equably; viz. that if the heat be increaſed gradually by one degree, two degrees, three degrees, &c. the fluid thus heated would expand its bulk by a certain quantity, then by twice that quantity, three times that quantity, and ſo on. But this is not the caſe, and every fluid ſeems to follow a particular law of expanſion.

Mercury ſeems to expand more equably than any other fluid *. Yet its increments of bulk are not quite

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* It will be neceſſary to ſhew how this irregularity may be aſcertained.—All the reaſoning and all the phenomena ariſing

quite proportional to the increments of heat. With other fluids the irregularity of expanſion is very conſiderable.

One

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ariſing from the mixtures of fluids, have eſtabliſhed the propoſition, that *when equal quantities of the ſame ſort of fluid, but differently heated, are mixed together, the temperature of the mixture is a mean proportional between the temperatures of the ſeparate parcels.* Now if a thermometer, having ſhewn the temperatures of the ſeparate parcels, on being placed into the mixture, does alſo ſhew an arithmetical mean between the ſeparate temperatures, you may conclude that the liquor, of which the thermometer is made, expands equably through the degrees about that temperature, and thus by trying ſimilar experiments in different temperatures, the law of the expanſibility of that fluid will be aſcertained.

Thus, if the thermometer being placed ſucceſſively into two equal quantities of water, ſhews 40° in one parcel, and 60° in the other; mix the two parcels of water, and if the thermometer, being placed in the mixture, ſhews 50°, you may conclude that its fluid has expanded equably; if it ſhews leſs than 50°, or more than 50°, you may conclude that its expanſion is not ſo great, or greater, &c.

Mr. De Luc has, with great care and aſſiduity, aſcertained the expanſibility of mercury, or rather the real quantities of heat which are required to expand mercury arithmetically. Theſe are expreſſed in the following table, the firſt column of which contains the degrees of Reaumur's ſcale, from five to five, which are equal parts; the ſecond ſhews the real quantities of heat which are required to raiſe the mercury to the correſponding degrees, where z is a fixt but unknown quantity; and the third column ſhews the differences of thoſe quantities. (De Luc's Recher. ſur les Modif. de l'Atmoſphere, 1772, p. 309.)

Point

One cubic inch of mercury, or one meaſure whatever of it at 32° of temperature, when heated to the temperature

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	Mercurial thermometers.	Real quantities of heat.	Real differences of heat correſponding to the variations of the mercur. therm. from 5 to 5 deg.
Point of boiling water	80°	z + 80,00	
	75	z + 75,28	— 4,72
	70	z + 70,56	— 4,72
	65	z + 65,77	— 4,79
	60	z + 60,96	— 4,81
	55	z + 56,15	— 4,81
	50	z + 51,26	— 4,89
	45	z + 46,37	— 4,89
	40	z + 41,40	— 4,97
	35	z + 36,40	— 5,00
	30	z + 31,32	— 5,08
	25	z + 26,22	— 5,10
	20	z + 21,12	— 5,10
	15	z + 15,94	— 5,18
	10	z + 10,74	— 5,20
	5	z + 5,43	— 5,31
Point of melting ice	0	z.	— 5,43

From the third column, it appears that the differences of heat requiſite to make equal and progreſſive additions to the bulk of the mercury, though not exactly equal, yet they are not very far from the ratio of equality. With other fluids the irregularities are much greater; as will appear from the following table, which contains the expanſions of the principal fluids that have been ſubjected to ſuch experiments, according to Mr. De Luc's obſervations.

In

temperature of boiling water; viz. at 212°, will be found increaſed in bulk by the quantity 0,01836. This fluid metal boils and becomes a vapour at 600° of Fahrenheit's thermometer, and it becomes a ſolid at —40°; viz. 72° below melting ice. Below that point; viz. —40°, it contracts irregularly. See Mr. Hutching's Experiments in the Philoſophical Tranſactions for 1783, Art. XX; alſo Art. XXI.

Spirit of wine boils at about 180°, and the pureſt probably never freezes. When brandy, or a mixture of water and ſpirit freezes, it is the water that becomes ſolid, but the ſpirit will be found collected together in one or more bubbles, in ſome part of the ice.

The extenſive uſe and influence of water both in natural and artificial affairs, renders it neceſſary to be more particular with reſpect to its expanſibility, and to the elaſtic force it acquires by being heated, &c.

The expanſibility of water forms a ſingular deviation from an otherwiſe general law of nature; for though

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In order to comprehend the meaning of this table, it muſt be underſtood that different thermometers (each being filled with a particular fluid, ſuch as is mentioned at the top of the columns, and each being divided into 80 equal parts between the freezing and the boiling water points) are placed with their bulbs in the ſame veſſel full of water, and that the water is gradually heated. Then when the mercurial thermometer though every other ſubſtance, as far as we know, is continually expanded by heat and contracted by cold; yet water is expanded by heat from about 40° of Fahrenheit's thermometer upwards; but below 40° its bulk is expanded by a farther decreaſe of heat, or increaſe of cold (ſee p. 86. vol. II.) and, in fact, ice is lighter than water, ſo as to float

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mometer is at 5°, 10°, 15°, &c. the ſurfaces of the fluids in the other thermometers will be found at the degrees which ſtand on the ſame levels; for inſtance, when the mercurial thermometer ſtands at 40°, the water thermometer will be found to ſtand at 20°,5; the ſpirit thermometer will be found to ſtand at 35°, the oil thermometer at 39°,2, &c.

Mercury.	Water.	Water ſaturated with ſalt.	Alcohol.	3 parts of alcohol, and 1 of water.	Equal parts of alcohol and water.	1 part of alcohol and 3 of water.	Oil of olives.
B.W. 80	80,0	80,0	80,0	80,0	80,0	80,0	80,0
75	71,0	74,1	73,8	73,7	73,2	71,6	74,6
70	62,0	68,4	67,6	67,5	66,7	62,9	69,4
65	53,5	62,6	61,5	61,5	60,6	55,2	64,4
60	45,8	57,1	55,5	55,8	54,8	47,7	59,3
55	38,5	51,7	50,3	50,2	49,1	40,6	54,2
50	32,0	46,6	45,1	44,9	43,6	34,4	49,2
45	26,1	41,2	40,0	39,7	38,4	28,4	44,0
40	20,5	36,3	35,0	34,8	33,3	23,0	39,2
35	15,9	31,3	30,1	29,8	28,4	18,0	34,2
30	11,2	26,5	25,5	25,2	23,9	13,5	29,3
25	7,3	21,9	20,9	20,7	19,4	9,4	24,3
20	4,1	17,3	16,5	16,2	15,3	6,1	19,3
15	1,6	12,8	12,0	11,8	11,1	3,4	14,4
10	0,2	8,4	7,9	7,7	7,1	1,4	9,5
5	0,4	4,2	3,9	3,8	3,4	0,1	4,7
Freez. 0	0,0	0,0		0,0	0,0	0,0	0,0
5		4,1					
10		8,0					

upon it; the ſpecific gravity of ice being to that of water nearly as 7 to 8; whereas the ice of oil is heavier than fluid oil, and ſinks in it.

The bulk of water from the moſt contracted ſtate of that fluid, which is at 40°, increaſes continually; but the increaſe is not very regular; for inſtance, the increaſe of bulk from 180° to 212°, is conſiderably greater than from 40° to 72°. If the bulk of water at 40° be called 1, its bulk at 212° will be 1,04785. After that degree of heat, water becomes vapour; viz. an elaſtic fluid, and the formation of this elaſtic fluid on the ſides of the veſſel within the water, forms the bubbles, the eſcape of which conſtitutes the boiling. Beyond that point the water cannot be heated; for all the additional heat combines with the water, and renders it vapour, which is elaſtic enough to overcome the mean preſſure of the atmoſphere. Water is at leaſt 2000 times denſer than vapour. When water is cauſed to boil on a common fire, the heat, which is communicated, cannot at once convert all the water into ſteam; but if the quantity of water be ſmall in proportion to the quantity of heat which can be communicated in a given time, then the converſion of water into vapour is much more expeditious, and indeed it may be rendered inſtantaneous; in which caſe it produces a very great expanſion or an exploſion. This happens with dreadful effects, when water falls upon large quantities of red hot or fuſed metals. Count Rumford juſtly attributes the vaſt force of gunpowder, to the ſudden converſion into vapour of that quantity of water which naturally enters into the compoſition of that powder *.

At 212° of temperature, water can entirely overcome the mean preſſure of the atmoſphere. Beyond that degree the vapour is expanded farther and farther, or becomes more and more elaſtic in proportion as it is heated to a greater and greater degree. But below 212° the water can in part overcome the preſſure of the atmoſphere; and, in fact, vapour is ſeen to proceed from a quantity of water long before its boiling.

The different powers of overcoming the preſſure of the atmoſphere at different temperatures, have been aſcertained with ſufficient accuracy within certain limits, principally by means of the following apparatus †.

A, fig. 5. Plate XVIII. is a veſſel placed upon a ſmall furnace B. It has three apertures; viz. *o*, to which the bent and open glaſs tube *o t g r* is fitted; the hole *s*, to which a thermometer *t h* is cloſely adapted, and the tube *x x*, which has the ſtop cock *b*. The lower part *m g z* of the glaſs

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* See his very ingenious paper and calculation in the Philoſophical Tranſactions for 1797. Art. XII.

† This method was contrived and uſed by the Chevalier de Bettancourt. See De Prony's Archit. Hydraul. vol. I. p. 557.

tube

tube is filled with quickſilver. This veſſel A, when the ſtop-cock is cloſed, has no communication with the external air; therefore it is evident that if the air be rarefied within the veſſel, the external preſſure of the atmoſphere will preſs the mercury down into the leg *r g*, and of courſe will force it to riſe into the leg *g k*; ſo that the difference of perpendicular altitude between the ſurfaces of the mercury in the two legs ſhews the degree of rarefaction within the veſſel, or the difference of preſſure between the internal and the external air. (See what has been ſaid with reſpect to the gauges of the air-pump in vol. II. p. 485, and following.) On the contrary, if the elaſticity of the fluid within the veſſel be increaſed, the mercury will be lowered in the leg *kg*, and will be raiſed in the leg *g r*. Then the difference of altitude between the ſurfaces of the mercury in the two legs ſhews the force of the elaſtic fluid within the veſſel; ſo that when that difference of perpendicular altitude is equal to the actual altitude of the mercury in the barometer, you may conclude that the force of the elaſtic fluid within the veſſel is equal to the preſſure of the atmoſphere, &c.

Now, when ſome water is placed in the veſſel A, and is heated, the temperature of it is indicated by the thermometer *th*, the ſcale of which projects out of the veſſel; and the correſpondent force of the vapour is indicated by the elevation of the mercury in the leg *g r* above the ſurface of the mercury in the leg *k g* *.

As the vapour of water, in order to aſſume the elaſtic form, muſt overcome, more or leſs effectually, the preſſure of the atmoſphere, ſo the preſſure of the atmoſphere forms a manifeſt oppoſition to the reduction of water into vapour, or to its boiling. Therefore, according as that preſſure varies, viz. as the barometer is high or low, ſo the water requires a greater or leſs degree of heat, in order to

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* With reſpect to the reſults of the experiments, I ſhall only mention a few in the following table, from which the force for the intermediate degrees of heat may be eaſily conceived.—The firſt column contains the temperature of the water in degrees of Fahrenheit's ſcale; the ſecond contains the correſpondent altitudes of the mercury it ſupports in inches and decimals.

50°	0,106	
100	1,600	
150	6,715	
160	8,740	
170	11,405	
180	14,709	
190	18,227	
200	22,703	
212	29,89	ſuppoſing the barometer to ſtand at its mean altitude, viz. 29,89.

Beyond the boiling point every additional 30° of heat nearly double the elaſticity of ſteam; ſo that at the temperature of 242°, the elaſtic force of ſteam is equal to the preſſure of two atmoſpheres; at 272° it is equal to four atmoſpheres; at 302° it is equal to eight atmoſpheres, &c.

boil.

boil. Hence, upon mountains water boils at a lower temperature than on the plains *, and in cloſed veſſels, or under an additional preſſure, water can be heated to a much greater degree than 212° †.

The ſingular property of water, viz. that in cooling from the 40th degree downwards, it ex-

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* The preciſe degrees of heat (Fahrenheit's thermometer) at which water will boil at different altitudes of the barometer, both according to Mr. De Luc's, and Sir G. Shuckburg's obſervations, are ſtated in the following table.

Height of the barometer.	Heat of boiling water, according to	
	Mr. De Luc.	Sir G. Sh.
26,	205,17	204,91
26,5	206,07	205,82
27,	206,96	206,73
27,5	207,84	207,63
28,	208,69	208,25
28,5	209,55	209,41
29,	210,38	210,28
29,5	210,20	211,15
30,	212,00	212,00
30,5	212,79	212,85
31,	213,57	213,69

† Water heated in a cloſed ſtrong veſſel may be rendered even red-hot; in which ſtate it acquires a prodigious expanſive force, as alſo a diſſolving power, ſuch indeed as to diſſolve even bones. It is from this property that a ſtrong veſſel fit for this experiment, and capable of being accurately cloſed, has been called a *digeſter*, or from its inventor *Papin's digeſter*.

pands, and becomes lighter and lighter, in proportion as it becomes colder and colder, is a moſt ſtriking inſtance of the wiſdom of the Creator, and is a circumſtance of immenſe conſequence to the very exiſtence of animal and vegetable life.

A quantity of fluid water is indiſpenſably neceſſary both to animals and to vegetables at all times of the year. When in winter the cold air freezes the ſurface of water, that effect ſeldom penetrates lower than two or three feet; below that depth the water continues fluid, and the cruſt of ice itſelf contributes to preſerve its fluidity. The heat of the earth which has been acquired during the ſummer, undoubtedly prevents the formation of ice beyond a certain depth. But if water in cooling had continued to increaſe in ſpecific gravity, and had ice been actually heavier than water, the heat of the earth would not have ſufficed to prevent the total freezing of all the waters of lakes, ſeas, &c. "For," *ſays an eloquent modern writer*, "as the particles of "water, on being cooled at the ſurface, would in "conſequence of the increaſe of their ſpecific gravity, on parting with a portion of their heat, immediately deſcend to the bottom, the greateſt "part of the heat accumulated during the ſummer in the earth, on which the water repoſes, "would be carried off and loſt before the water "began to freeze; and when ice was once formed, "its thickneſs would increaſe with great rapidity, "and would continue increaſing during the whole

" winter; and it ſeems very probable that in cli-
" mates which are now temperate, the water in
" the large lakes would be frozen to ſuch a depth
" in the courſe of a ſevere winter, that the heat of
" the enſuing ſummer would not be ſufficient to
" thaw them; and ſhould this once happen, the
" following winter would hardly fail to change the
" whole maſs of its waters to one ſolid body of
" ice, which never more could recover its liquid
" form, but muſt remain immoveable till the end
" of time *."

It has been already remarked, that though ice melts at 32°, yet water does not freeze at 32°, but it requires to be cooled ſome degrees lower before it will acquire the ſolid form. This is alſo the caſe with mercury; viz. it bears to be cooled ſome degrees below — 40°.

Several facts which have been obſerved by various experimenters, have thrown a good deal of light upon this ſingular phenomenon, yet the real cauſe of it is far from being clearly underſtood.

It has been frequently aſſerted, that boiled water freezes ſooner than unboiled water; and this may be true with reſpect to impure waters, becauſe as a mixture of ſalts, or acids, or earths, or alkalies, &c.

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* Count Rumford's 7th Eſſay, chap. III. wherein this ſubject is conſidered at large under different points of view.

renders water leſs liable to be frozen than pure water, the boiling may cauſe a precipitation or evaporation of the ſalt, earth, &c. and thus, by leaving the water in a purer ſtate, may render it more capable of being frozen. But the boiling of pure (viz. diſtilled) water, which ſeems to do nothing more than deprive it of air, certainly renders it leſs apt to freeze; for water, thus deprived of air has been often cooled ſeveral degrees below 32°; viz. even ſo low as to 14°, before it would freeze [*].

When water has been cooled as many degrees below 212° as it will bear without freezing, the congelation in that caſe may be haſtened by various means, viz. by a ſudden ſtroke againſt the ſides of the veſſel, by touching the ſurface of the water with a piece of ice, by placing a largiſh piece of metal in contact with the outſide of the veſſel, &c. The water then will ſhoot into cryſtals in a very ſtriking manner, and will acquire the ſolid form, almoſt inſtantaneouſly; the thermometer, which has its bulb in it, riſing at the ſame time immediately to 32° [†].

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[*] Mr. De Luc's *Idées ſur la Meteoroligie*, tom. II. p. 105. Yet in the atmoſphere, water begins to freeze when the temperature of the atmoſphere is very little below 32°.

[†] For farther particulars reſpecting this property of water, as alſo for the conjectures which have been offered in explanation of it, ſee the Philoſophical Tranſactions, vol. for 1788. Art. X.

A ſimilar effect is produced by the freezing of quickſilver.

The admixture of ſaline and ſeveral other ſubſtances lower the freezing point of water; but it is impoſſible to examine the numerous facts which may be obſerved with reſpect to the infinite poſſible combinations of water with other ſubſtances; we ſhall, however, ſtate the principal phenomena which relate to the congelation of ſalt-water or ſea-water, which is of more general conſequence.

Sea-water, which at a mean may be ſaid to contain 1-28th of its weight of ſalt*, muſt be cooled to about 0° before it will freeze. A frigorific mixture of three parts of pounded ice, and two parts of common ſalt, which will lower the thermometer to —4°†, is quite ſufficient to freeze it.

A quantity of ſea-water is never entirely congealed, a portion of it does always remain fluid; and what is very remarkable, this fluid portion is incomparably more full of ſalt, and more nauſeous, than the frozen part; ſo that if the former be ſeparated, the latter, on being melted, will be found to contain much leſs ſalt, &c. than it did before the congelation. If this water of the *firſt purification* be again congealed, which requires leſs cold, it will

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* See Dr. Watſon's Chem. Eſſays, vol. II. Eſſay IV.

† The negative ſign, viz. a ſtroke before the number of degrees, means ſuch number of degrees below the 0 of the ſcale.

alſo leave a fluid portion, which will be found to contain a greater proportion of ſalt than the congealed part, and may be ſeparated from it. Thus by repeatedly freezing the ſame ſea-water, and ſeparating the fluid from the congealed part in every operation, you will at laſt obtain the water perfectly purified, and fit for drink and other purpoſes. Sea-water thus purified, by means of ſix ſucceſſive congelations, has been found perfectly ſweet, capable of diſſolving ſope, and ſo nearly of the ſpecific gravity of rain-water, that the former was to the latter as 7801 to 7800 *.

Theſe facts will eaſily explain why ſome navigators have found the ice of ſea-water, when melted, not good for drink, whilſt others have found it very ſweet and uſeful, as it proved to Captain Cook's expedition near the ſouth pole.

After the liquids, it will be neceſſary to notice the expanſibility of the aërial fluids, and here we muſt confine ourſelves almoſt entirely to common air; for the various experiments which have been made with other permanently elaſtic fluids are by no means concluſive; excepting their having proved that hydrogen gas is expanded by means of heat conſiderably more than common air.

The inſtrument in which the expanſion of air is tried has been called *manometer*, but in truth it is

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* See the Chevalier Lorgna's Experiments, concerning the purification of ſea-water.

only an air-thermometer, and, though rather larger, it is not however unlike the common thermometer; viz. it conſiſts of a tube five or ſix feet long, having a bulb at one end and open at the other. The bore of the tube is about a 20th of an inch in diameter. A ſmall quantity of quickſilver is placed in ſome part of the cavity of the tube, and the expanſion of the air of the bulb, when heated, forces the quickſilver to move towards the open end of the tube. The degree of heat to which the manometer is expoſed, is meaſured by means of a thermometer; the quantity of expanſion of the air is aſcertained by gauging the manometer, and making marks on the tube, which marks may indicate parts of the cavity of the tube that are proportional to the capacity of the manometer, as for inſtance, 100ths or 1000ths, &c. See fig. 6. Plate XVIII.

By placing the manometer horizontal or vertical, either with the bulb downwards or the bulb upwards, the air in it may be either left of the natural denſity, or it may be condenſed, or, laſtly, it may be rarefied; for when the manometer is horizontal, the quickſilver *a b* does neither preſs upon the air of the manometer, nor on that of the atmoſphere; when the bulb is downwards, the quickſilver *a b* preſſes upon the air of the manometer, and when the bulb is upwards, the quickſilver *a b* preſſes againſt, and counteracts, in ſome meaſure, the gravity of the atmoſphere. Hence this preſſure and this rarefaction of the air within the manometer

meter may be increaſed to any required degree by increaſing the quantity *a b* of the quickſilver within the tube; and thus the expanſibility of common, or of condenſed, or of rarefied air may be tried.

The expanſion of air by the ſame degrees of heat, differs according to its denſity, and to the quantity of moiſture it contains; nor are the increments of its bulk proportional to the degrees of temperature.

It appears from Col. Roy's very numerous experiments [*], that 1000 parts of air, of the denſity of the common atmoſphere, at 0° of heat, become 1484,21 at 212°, viz. are expanded 484,21 by 212° of heat.

1000 parts of air, loaded with $2\frac{1}{2}$ atmoſpheres, are expanded 434 of thoſe parts, by 212° of heat.

1000 parts of air preſſed only with $\frac{5}{6}$ ths of an atmoſphere, are expanded nearly 484 of thoſe parts by 212° of heat.

1000 parts of air preſſed with $\frac{1}{5}$ th of an atmoſphere, are expanded about 141 parts by 180° of heat; viz. from the freezing to the boiling point.

"From theſe laſt experiments," ſays Col. Roy, "it would ſeem, that the particles of air may be "ſo far removed from each other, by the diminution of preſſure, as to loſe a very great part of "their elaſtic force."

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[*] Philoſophical Tranſactions, vol. LXVII. Article XXXIV.

The abovementioned expanſions are by no means regular; viz. they are not proportional to the number of degrees of heat. The maximum of expanſion takes place between 52° and 72°, and the minimum is conſtantly at the boiling point of water.

Moiſt air expands vaſtly more than dry air, eſpecially when it approaches the boiling point of water; ſo that between 192° and 212° moiſt air expands about 8 or 9 times as much as dry air in ſimilar circumſtances.

From all what has been ſaid with reſpect to the expanſion of fluids, it appears that on account of the great irregularity of the rate of expanſion, mercury and ſpirit of wine are the only two fluids which can be uſed for thermometers; obſerving that ſome compenſation muſt be made in the ſcale of the ſpirit thermometer, in order to make it correſpond with the ſcale of the mercurial thermometer. But the mercurial thermometer cannot indicate a temperature higher than 600°. Hence various ingenious perſons have endeavoured to contrive inſtruments capable of indicating the higher degrees of heat, which would be of great uſe in philoſophy, chemiſtry, and various arts*; but the only uſeful contrivance

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* It is mentioned by De Magellan, in his *Eſſay ſur la nouvelle Théorie du Feu élementaire*, 1780, that Mr. Achard of Berlin had contrived and executed a thermometer capable of

contrivance of this ſort was made by the late Mr. Wedgwood. This ingenious gentleman applied to the meaſuring of high degrees of heat, a ſingular property of argillaceous bodies, a property which obtains more or leſs in every kind of them, as far as has been examined. This property is, that an argillaceous ſubſtance, when expoſed to a fire, is diminiſhed in bulk by it, nor does the bulk increaſe again after cooling; and this diminution of bulk is proportionate to the degree of heat to which the ſubſtance has been expoſed.

This property may ſeem to be a deviation from the general rule, viz. that heat expands all ſorts of bodies, and that a diminution of heat enables them to contract their dimenſions; but in this caſe it muſt be conſidered that the clay-pieces contract and remain contracted, becauſe ſome ſubſtance, viz. water and an aëriform fluid, is ſeparated from them by the action of the fire.

Mr. Wedgwood's thermometer, or apparatus for meaſuring the high degrees of heat, conſiſts of ſmall

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of meaſuring the degrees of heat from 212° to a conſiderable number beyond 600°; the tube and bulb of this thermometer are ſaid to conſiſt of a ſemi-tranſparent porcelain, and to be filled with a mixture of two parts of biſmuth, one of lead, and one of tin, which metallic mixture melts at about the point of boiling water, and is afterwards expanded by an increaſe of heat. But I never ſaw one of thoſe thermometers.

pieces of clay of a determined length, which are to be placed in the furnace, crucible, &c. whoſe degree of heat is to be aſcertained, and of a gauge to meaſure the contracted dimenſions of the clay-pieces, after they have been expoſed to the fire.

Fig. 7. Plate XVIII. repreſents the gauge, which is either of braſs or of porcelain. Fig. 8. repreſents a ſection of the ſame; and the letters refer to the like parts in both figures. EFHG is a ſmooth flat plate; AC, BD, are two rulers or flat pieces, a quarter of an inch thick, and fixed faſt upon the plate, ſo as to form a converging canal ABCD, whoſe width at CD is three-fifths of the width at AB. The whole length of the canal from AB to CD, is divided into 240 equal parts, and the diviſions are numbered from the wider end. It is evident that if a body, ſo adjuſted as to fit exactly the wider end of this canal, be afterwards diminiſhed in its bulk by the action of fire (as the thermometrical pieces, which will be deſcribed in the next paragraph) it may then be paſſed further in the canal, and more ſo, according as the diminution is greater.

The thermometrical pieces are ſmall cylinders of clay [*], a little flattened on one ſide. They are nearly

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[*] As different ſpecimens of clay are contracted differently by the like degrees of heat, Mr. Wedgwood endeavoured to find a ſort of argillaceous ſubſtance, which might be conſtant

nearly as much in diameter as they are in length. When one of theſe pieces is to be uſed, it is proper to meaſure it firſt by placing it in the gauge at AB; for ſometimes thoſe pieces are a few degrees larger or ſmaller than the diſtance A B, which exceſs or defect being aſcertained, muſt afterwards be allowed for. P repreſents one of theſe pieces ſet in the gauge for meaſurement.

The piece is then placed into the furnace, or crucible*, and if it be taken out either at the end of the operation, or at any period, and, when grown cold, be meaſured by ſliding it as far as it will go, into the canal of the gauge, the number of diviſions

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conſtant in its contracting property. After a variety of trials he found that two parts of the Cornwall porcelain clay, and one part of the earth of alum, formed a ſubſtance poſſeſſed of the deſired property.

The alum earth is prepared by diſſolving the alum in water, precipitating with a ſolution of fixed alkali, and waſhing the earth repeatedly with large quantities of boiling water.

The two earths muſt be well mixed together, then the paſte is formed into a cylinder by means of a mould, and cut to the proper length. They are alſo expoſed to a low fire, viz. barely red-hot, in order to give them ſome hardneſs.

* In certain caſes it will be proper not to expoſe the thermometrical piece by itſelf, but to place it in a ſmall crucible or caſe of crucible earth, and expoſe it with the caſe to the fire; which prevents the adheſion of extraneous matter to the piece, &c.

againſt the place where it ſtops will ſhew the contracted dimenſions of the piece, and of courſe the degree of heat to which it has been expoſed. It will be found that theſe pieces will go very little beyond 0 in the canal, if they have been expoſed to a viſible red heat; will go to 27° if they have been expoſed to the heat in which copper melts; to about 90° if expoſed to the welding heat of iron; about 160° if expoſed to the greateſt heat that can be produced with charred pit-coal in a well conſtructed common air-furnace, &c.

The ſame thermometrical piece which has been uſed before, may be uſed again for higher degrees of heat, but not for lower degrees.

It is now neceſſary to ſhew the correſpondence between the ſcale of this, and the ſcale of Fahrenheit's mercurial thermometer.

As the mercurial thermometer cannot ſhew a temperature higher than 600°, and Wedgwood's thermometer cannot ſhew a temperature lower than red heat, which is by ſeveral degrees higher than 600°, therefore it was neceſſary to contrive a meaſure for the intermediate degrees, and which might reach ſome degrees below 600°, and ſome degrees above the temperature of a red heat. Mr. Wedgwood choſe a piece of ſilver, the expanſion of which meaſured in a gauge made for the purpoſe, ſimilar to the gauge, fig. 7. might indicate the degrees of temperature between the two thermometers; with this inſtrument he firſt found the correſpondence between the degrees of Fahrenheit's ſcale and the laſt-mentioned gauge, by placing them alternately in water of the temperature of 50°, and in boiling water. Then he found the correſpondence between the degrees of the gauge of the ſilver piece, and that of the earthen thermometrical pieces, by placing them both at the ſame time into different and higher degrees of heat; laſtly, by computation from thoſe reſults, he determined the correſpondence between the degrees of Fahrenheit's ſcale and thoſe of his own thermometrical gauge *.

It was found that one degree of Wedgwood's thermometer is equal to 130° of Fahrenheit's; and that the 0 of Wedgwood's coincides with the 1077,°5 of Fahrenheit's; from which data a compariſon of the two thermometers may be made, or rather of the imaginary extenſions of their two ſcales; for, in fact, Fahrenheit's thermometer cannot ſhew higher than 600°; and Wedgwood's

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* If it be aſked why could not the abovementioned gauge with the ſilver piece be uſed, in chemical and other proceſſes, for meaſuring the intermediate degrees between the thermometers of Fahrenheit and Wedgwood? The anſwer is, that the piece of ſilver, after being expanded by heat, does not remain in that ſtate, but is contracted in cooling; therefore it muſt be meaſured whilſt hot; and for this purpoſe the gauge itſelf muſt be actually expoſed to the ſame degree of heat; which is attended with very great inconveniences.

cannot reach near ſo low. It is likewiſe to be obſerved that the degrees of Wedgwood's ſcale are ſuppoſed to ſhew equal increments of heat; whereas in truth we do not know whether the clay thermometrical pieces contract in proportion to the increments of heat; which ſhews that, though this is the beſt known thermometer for meaſuring the higher degrees of heat, yet an improvement of the ſame, or ſome other more manageable and more accurate contrivance, is highly deſirable.

Upon the whole it appears, that the ſpirit thermometer enables us to meaſure the degrees of heat as low as has ever been experienced, either naturally, or by artificial cooling; that the mercurial thermometer enables us to meaſure the heat from — 40° to 600°; and that Wedgwood's thermometer enables us to meaſure from a red heat up to the farther extent of that ſcale, viz. to its 240th degree, which is reckoned equivalent to 32277° of Fahrenheit's ſcale*.

The following Table contains the correſpondence between Fahrenheit's and Wedgwood's thermometer; and it exhibits a conſiderable number of peculiar effects or phenomena, which have been found to take place at particular degrees of heat.

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* For farther particulars reſpecting Mr. Wedgwood's thermometer, ſee the Philoſophical Tranſactions, vol. LXXII. Art. XIX. vol. LXXIV. Art. XXVII. and vol. LXXVI. Art. XXII.

	Fahren.	Wedg.
Extremity of the ſcale of Wedgwood's thermometer	32277°	240°
Greateſt heat of an air furnace 8 inches in diameter, which neither melted nor ſoftened Nankeen porcelain	21877	160
Chineſe porcelain ſoftened beſt ſort	21357	156
Chineſe porcelain ſoftened infer. ſort	15600	120
Pig iron thoroughly melted for caſting	20200	150
Briſtol porcelain withſtood	18627	135
Pig iron begins to melt	17977	130
Greateſt heat of a common ſmith's forge	17327	125
Plate glaſs furnace (ſtrongeſt heat)	17197	124
Bow porcelain vitrifies	16807	121
Flint glaſs furnace (ſtrongeſt heat)	15897	114
Derby porcelain vitrifies	15637	112
Chelſea porcelain vitrifies	14727	105
Stone ware, or *pots de gres*, baked in	14337	102
Worceſter porcelain vitrifies	13297	94
Welding heat of iron greateſt	13427	95
Welding heat of iron leaſt	12777	90
Cream-coloured ware baked in	12257	86
Flint glaſs furnace (weak heat)	10177	70
Working heat of plate glaſs	8487	57
Delft ware baked in	6467	41
Fine gold melts	5237	32
Settling heat of flint glaſs	4847	29
Fine ſilver melts	4717	28
Swediſh copper melts	4587	27
Braſs melts	3807	21

	Fahren.	Wedg.
Heat, by which enamel colours are burnt on - - - - -	1857°	6°
Red-heat fully viſible in day-light -	1077	0
Mercury boils, alſo linſeed and other expreſſed oils boil - - -	600	
The ſurface of poliſhed ſteel acquires a uniform deep blue colour - -	580	
Oil of turpentine boils - - -	560	
Sulphuric acid boils - - -	546	
Lead melts - - - - -	540	
The ſurface of poliſhed ſteel acquires a pale ſtraw colour*; and is the beſt heat to which hardened blades of pen-knives and other tools with a fine edge, muſt be brought down for a proper temper. Alſo biſmuth melts, and likewiſe a mixture of 4 parts of lead and one of tin melts -	460	
Tin melts † - - - - -	408	
Heat, to which the hardened blades of razors ſhould be brought down for a fine temper - - - -	430	
A mixture of 3 parts of tin and 2 of lead melts; alſo a mixture of 2 parts of tin and one of biſmuth melts -	334	

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[*] The intermediate degrees of heat between 460° and 580°, produce upon ſteel the ſucceſſive ſhades of colour between pale ſtraw and deep blue colour.

[†] " I have (Mr. Cavendiſh ſays in the Philoſophical

	Fahren.
A compound of equal parts of tin and biſmuth melts	283°
Nitric acid boils *	242
A ſaturated ſolution of ſalt boils †	218
Water boils (the barometer being at 30 inches); alſo a compound of 5 parts of biſmuth, 3 parts of tin, and 2 parts of lead, melts	212
A compound of 3 parts of tin, 5 of lead, and 8 of biſmuth, melts rather below	210
Alkohol boils	174
Serum of blood begins to coagulate; alſo albumen, or the white of an egg, coagulates	156
Bees wax melts	142
Feveriſh heat from 107° to	112
Heat fit for the hatching of hen's eggs	108
The moſt uſual heat for a pleaſant bath	106
Heat of the interior bath of Edinburgh	100

“ Tranſactions, vol. 73d, p. 313) formerly kept a thermometer in melted tin and lead, till they became ſolid; the thermometer remained perfectly ſtationary, from the time the metal began to harden round the ſides of the pot till it was entirely ſolid; but I could not perceive it to ſink at all below that point, and riſe up to it when the metal began to harden.”

* Concerning the freezing point of this acid, ſee the Phil. Tranſ. vol. 76th, Art. XIII.

† Some air is expelled before the heat of 212.

	Fahren.
Animal heat, or blood heat, from 96° to	100°
Water freezes, or rather ice begins to melt	32
Milk freezes	30
Vinegar freezes at about	28
Human blood freezes	25
Strong wines freeze at about	20
A mixture of 1 part of alkohol and 3 parts of water freezes	7
A mixture of alkohol and water in equal quantities freezes	—7
A mixture of 2 parts of alkohol and 1 of water freezes	—11
Mercury congeals *	—39

Solids

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* In aſſuming the ſolid form, mercury contracts its bulk irregularly. Upon the whole it ſeems to contract about $\frac{1}{23}$d of its bulk; but it is impoſſible to ſay how much more it may contract by a greater cold. Mercury may be cooled ſome degrees below its freezing point, before it aſſumes the ſolid form; but as ſoon as it begins to harden, the thermometer riſes to its freezing point, which, from a variety of the moſt accurate experiments made by Mr. Hutchins at Hudſon's Bay, appeared upon his thermometers to be —40. "But (Mr. Cavendiſh obſerves in the Phil. Tranſ. vol. 73d, p. 321) "as it appeared from the examination of this thermometer, "after it came home, that —40 thereon anſwers to —38° $\frac{2}{3}$ "on a thermometer adjuſted in the manner recommended "by the committee of the Royal Society; it follows, that "all the experiments agree in ſhewing that the true point at

Solids are expanded by heat much leſs than fluids; and, indeed, there ſeems to be that law in nature, namely, that in general bodies of leſs denſity are expanded more than other bodies of greater denſity. This law, however, has ſeveral exceptions, eſpecially amongſt the ſolids. Thus hydrogen gas is expanded more than common air; common air more than ſpirit of wine; ſpirit of wine more than water; water more than mercury; mercury more than iron; but iron leſs than tin, though tin is ſpecifically lighter than iron.

The inſtruments for meaſuring the expanſions of ſolids, have been called *pyrometers*, (viz. meaſurers of fire); and they have been made of a great variety of ſhapes. The whole conſiſts of a machine capable of rendering the ſmall expanſions of ſolids apparent to the obſerver, and of an apparatus fit to heat the bodies under examination to a determined degree. The moſt uſual, and, indeed, the moſt eligible, mode of heating the bodies, is to place them in water, wherein a thermometer is placed, and to heat the water by means of lamps. The ſmall expanſions

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"which quickſilver freezes, is —38° ⅔, or in whole numbers, "39° below nothing."

In becoming ſolid, mercury ſometimes ſhoots into chryſtals or longitudinal filaments like pins. Congealed mercury poſſeſſes conſiderable ductility; but it does not ſeem to be perfectly malleable. See the Phil. Tranſ. vol. 73d, Part II.

of the heated ſolids have been rendered viſible, 1ſt, by multiplying wheels, or by leavers, or by fine ſcrews, which render a ſmall motion communicated to one end of the mechaniſm productive of a great movement at the other end; and 2dly, by magnifying the ſmall expanſion through microſcopes; which, upon the whole, ſeems to be by far the moſt certain and the moſt manageable method; for with wheels and pinions, and even with levers or ſcrews, there is always ſome equivocal motion, ariſing from the looſe connection of teeth and pinions, or from the ſtreſs and bending of other parts *.

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* Muſſchembroek ſeems to have been the firſt inventor of the pyrometer. See his Pyrometer, with alterations and improvements by Deſagulier, in Deſagulier's Exp. Phil. vol. I. p. 421.

Mr. Ellicot contrived a different mechaniſm, which is deſcribed in the Phil. Tranſ. N. 443. With that pyrometer he determined the proportional expanſions of ſeven metallic ſubſtances, produced by the ſame increaſe of temperature. They are as follows;

Gold.	Silver.	Braſs.	Copper.	Iron.	Steel.	Lead.
73	103	95	89	60	56	149

A very ſimple pyrometer, more uſeful for ſhewing the expanſion of metals in a courſe of lectures, than for accuracy of meaſurements, is deſcribed by Ferguſon in the ſupplement to his lectures.

Mr. Smeaton contrived a pyrometer, which is vaſtly ſuperior to any that had been conſtructed before, either in this

The beſt inſtrument of the kind, in point of accuracy, is undoubtedly Mr. Ramſden's pyrometer, of whoſe conſtruction I ſhall now give a ſhort idea; referring the reader for farther particulars to the original and particular deſcription in the Philoſophical Tranſactions.

The metallic bar, whoſe expanſion is to be meaſured, and which may be even five feet long, is placed in a copper trough little longer than five feet; and this is placed over 12 ſpirit lamps, the flames of which can heat the water of that trough fully to the boiling point, and of courſe heat the bar which is plunged in it.

Two other wooden troughs, alſo full of water, are placed parallel to, and at a little diſtance from, the copper one. Each of theſe contains a caſt iron priſmatic bar; to the ends of one of thoſe bars two microſcopes are faſtened in an horizontal ſituation, perpendicularly to the bars. One of thoſe microſcopes is furniſhed with a micrometer, or mechaniſm,

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country or elſewhere, and with it he determined the expanſibility of ſeveral ſubſtances to a conſiderable degree of accuracy. See the Phil. Tranſ. vol. 48th. See alſo De Luc's pyrometer in the Phil. Tranſ. vol. 68th. But all thoſe contrivances muſt be conſidered as inferior to a pyrometer which was contrived by the late very ingenious Mr. Jeſſey Ramſden; of which an accurate and minute deſcription is given by General Roy, in the 75th vol. of the Philoſophical Tranſactions.

chaniſm, to meaſure the magnified image of an object; the other microſcope has a ſimple mark. Now, without entering into any particular detail, which would not be proper, previous to the deſcription of microſcopes, I ſhall only ſay, that the parts of the microſcopes, as alſo the proper marks for meaſurement, are ſo ſeparated and diſpoſed, partly upon the ends of the caſt-iron rods, and partly upon the ends of the rod under examination, that if any of them be lengthened or ſhortened, that alteration is clearly perceived through the microſcopes, and may be meaſured by means of the micrometer. It follows, that if the temperature of the caſt-iron priſmatic bars be kept unaltered, whilſt that of the bar under examination is increaſed, then the increaſe of length, which is meaſured by the micromoter, muſt be attributed to that bar only; and by this means the expanſions of ſeven ſubſtances were aſcertained *.

The following table ſhews in parts of an inch how much a foot length of different ſubſtances is expanded by 180° of heat, between the freezing and boiling point of water. To the firſt ſeven ſubſtances (having been examined in Mr. Ramſden's, which is by far the moſt accurate, pyrometer), I have added the expanſions for a ſingle degree of heat. The reſt were determined by Mr. Smeaton with his pyromoter.

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* The table of thoſe expanſions is in page 480 of the 75th vol. of the Phil. Tranſ.

Standard

	Fahrenheit's ſcale.	
	By 1°	By 180°
Standard braſs ſcale, ſuppoſed to be Hamburgh braſs - - -	0,0001237	0,0222646
Engliſh plate braſs, in form of a rod - - -	0,0001262	0,0227136
Engliſh plate braſs, in form of a trough - -	0,0001263	0,0227386
Steel rod - - -	0,0000763	0,0137368
Caſt iron priſm - -	0,0000740	0,0133126
Glaſs tube * - -	0,0000517	0,0093138
Solid glaſs rod * - -	0,0000539	0,0096944
White glaſs barometer tube * -		0,0100
Martial regulus of antimony -		0,0130
Bliſtered ſteel - - - -		0,0138
Hard ſteel - - - -		0,0147
Iron - - - - -		0,0151
Biſmuth - - - - -		0,0167
Copper hammered - - -		0,0204
Copper 8 parts with tin one -		0,0218
Caſt braſs - - - -		0,0225
Braſs 16 parts with tin one -		0,0229
Braſs wire - - - -		0,0232

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* Sometimes glaſs tubes are extended more than ſolid glaſs rods; their dilatation, however, is not conſtant; for tubes of different diameters, or of different ſorts of glaſs, are expanded differently by the like degrees of heat. Phil. Tranſ. vol. 67th, p. 665.

Speculum metal - - - -	0,0232
Spelter ſolder, viz. braſs 2 parts, zinc one	0,0247
Fine pewter - - - - -	0,0274
Grain tin - - - - -	0,0298
Soft ſolder, viz. lead 2 parts, tin one	0,0301
Zinc 8 parts with tin one, a little hammered - - - - -	0,0323
Lead - - - - - -	0,0344
Zinc or ſpelter - - - -	0,0353
Zinc hammered half an inch per foot -	0,0373

Wood is not much expanded longitudinally, viz. in the direction of its fibres, by heat; and this is particularly the caſe with deal and other ſtraight grained wood. Probably upon the whole, the longitudinal expanſion of wood is leſs than that of glaſs. It has been obſerved, that very dry and ſeaſoned wood, if not expoſed to a very high or to a very low temperature, will expand in length pretty regularly; otherwiſe its expanſion by heat and contraction by cold are very irregular; for they ſeem to depend partly upon the heat, and partly upon the moiſture, which the wood acquires in certain circumſtances, and is deprived of in others*.

The expanſion and contraction of every ſubſtance by heat and cold, and the continual change of temperature, to which all the ſurface of the earth,

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* See Dr. Ritenhouſe's Experiments in the Tranſactions of the American Philoſophical Society.

with

with whatever thereon exiſts, is ſubject, ſhew that every particle of matter, every fibre of our bodies, metals, bricks, ſtones, fluids, &c. are all in continual motion, though thoſe movements may appear very ſmall to our ſenſes. Hence it is ſaid, that heat is the univerſal mover, and ſeems to animate the whole.

Some uſeful advantages in mechanics are derived from the knowledge of the various expanſibilities of bodies. Thus well-conſtructed clocks would be ſubject to a conſiderable imperfection, were not remedies pointed out by thoſe various expanſibilities. To deſcribe the mechaniſm of clocks, watches, &c. would be foreign to the ſubject of this work; but I ſhall endeavour briefly to ſhew the advantage which clock-making derives therefrom.

It is evident that when the pendulum of a clock grows longer, the time of vibration is lengthened, and of courſe the clock goes ſlower. The contrary happens when the pendulum grows ſhorter. Now a variety of contrivances to obviate this defect of clocks, &c. have been made by divers ingenious artiſts, ſuch as Graham, Harriſon, Ellicot, Berthoud, Cumming, Mudge, &c. which contrivances are all derived from the expanſibilities of bodies. The following two or three inſtances in the ſimpleſt mode of conſtruction, will give a ſufficient idea of the application.

A wooden rod for the pendulum of a clock is certainly better than a common metallic rod; the expanſion

panſion of the former being much leſs than that of the latter. A glaſs rod or tube is alſo preferable to metal; but the effects of the expanſibility of the glaſs tube may be entirely removed by this means, viz. by filling part of the tube with mercury. Suppoſe, for inſtance, that AB, fig. 9. Plate XVIII. is ſuch a tube ſuſpended at A, and filled with mercury from B to C; and let D be the centre of oſcillation of the tube. Now it is evident, that when the tube is extended by heat, the diſtance of the point D from A is increaſed; for inſtance, D comes to *d*; but the ſame heat which extends the tube, rarefies the mercury alſo, and extends its ſurface C to *c*; hence on account of this elevation, the centre of oſcillation of the mercury B*c*, which before ſtood at E, is raiſed to *e*, and of courſe the centre of oſcillation of both the tube and the quickſilver together remains in the ſame place; the centre of oſcillation of the one being raiſed as much as that of the other is depreſſed.

The ſame remedy may be obtained by a combination of bars of different metals, (which form what is called *a compound pendulum)*; and the following is the ſimpleſt, though not the moſt correct, and the moſt commodious, conſtruction. Fig. 10. Plate XVIII. repreſents a pendulum, conſiſting of two bars, AB, AC, of two different metals, of which AC is the moſt expanſible by heat. CD is a lever pinned at B and C to the extremities of the bars, and ſuſpending a weight or bob E. Now, if the two bars were expanded alike by heat, it is evident that the diſtance of the weight E, from the point of ſuſpenſion A, would be increaſed; but as AC is expanded more than AB, when the extremity B comes to *b*, the extremity C comes lower down, viz. to *c*; hence the lever CD is placed in the ſituation *cb*D; ſo that the extremity D remains in the ſame place it was before, and of courſe the diſtance EA remains unaltered. In thoſe caſes the lengths of the rods, levers, or (in the above inſtance of the glaſs tube) the quantity of mercury muſt be calculated and adjuſted according to the quantities of expanſions, lengths of the pendulums, &c.

Other contrivances, but upon the ſame principle of different expanſibility, have been applied to the beſt watches or time-pieces.

CHAPTER III.

OF THE CAPACITY OF BODIES FOR CALORIC, AND THEIR SPECIFIC CALORIC.

HEAT, or, according to the theory, caloric, cannot be accumulated and detained in any particular place or body, but it continually tends to expand itſelf over the adjacent bodies, till they are brought to the ſame temperature. Thus, if a piece of red-hot iron be placed amongſt other pieces of ſtone, metal, &c. in a colder ſtate; the heat will be communicated from the iron to the other bodies; to the neareſt firſt, and then to thoſe that are more remote; ſo that by degrees the iron loſes part of its heat, and the other bodies acquire it, until they all attain the ſame temperature; for though the caloric will paſs through certain bodies eaſier than through others; yet there is no body which can confine it effectually.

When homogeneous bodies, viz. parcels of the ſame ſort of ſubſtance, are placed in a higher temperature, or when they are unequally heated and brought into contact; the quantity of caloric which is communicated to, or abſorbed by, each of the bodies, is proportionate to the quantity of matter of each body reſpectively. And on the contrary, if they be placed in a lower temperature, the quantities of caloric which they loſe, are proportionate to their quantities of matter reſpectively. Thus, if two leaden balls of equal weights be placed in boiling water, they will be heated alike, or equal quantities of caloric will be communicated to them. If they be placed in cold water, they will be deprived of equal quantities of caloric. When a pound of water is mixed with another pound of water hotter than the former, the exceſs of heat which one of them has above the other will be divided into two; viz. it will be diſtributed equably amongſt the two pounds of water. If two pounds of water be mixed with one pound of hotter water, the exceſs of heat will be divided into three parts, viz. it will be diſtributed equably amongſt the three pounds of water: hence we derive an eaſy rule for determining the temperature of a mixture of homogeneous bodies, which poſſeſſed different known temperatures before the mixture. The rule is as follows:

Multiply the weight of each parcel or body by its peculiar temperature; add the products together, and divide the ſum of thoſe products by the ſum of the weights; the quotient is the temperature of the mixture.

Thus, if three pounds of water, whoſe temperature is 40°, be mixed with 9 pounds of water, whoſe temperature is 100°, the temperature of the mixture will be 85°; for 3 multiplied by 40° gives 120°, and

and 9 multiplied by 100°, gives 900°. The ſum of thoſe two products is 1020°, which being divided by the ſum of the pounds, viz. by 12, quotes 85°; and ſuch is the temperature of the mixture*.

Again, if 2 pounds of mercury at 40°, be mixed with 4 pounds of mercury at 60°, and 4 pounds

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* Several circumſtances, of which the following are the moſt eſſential, muſt be attended to in the performance of thoſe experiments.

1. The thermometers muſt have ſmall balls, and ſhould be ſo ſenſible as to indicate at leaſt quarters of each degree; and the quantities of the bodies concerned ſhould be pretty large, otherwiſe the dipping of the thermometer in the mixture introduces a third ſubſtance, namely, the mercury of the thermometer, which will alter the reſult conſiderably. The reſults however may be calculated by conſidering the veſſel, and the thermometer, as two of the bodies concerned in forming the mixture.

2. The heat of the mixture is hardly ever uniform throughout; therefore it will be proper to take the temperature of the bottom, of the middle, and of the upper part of the mixture; for a mean of thoſe three will give the temperature of the whole mixture.

3. As the mixture is loſing heat gradually, and as it will be hardly poſſible to put the thermometer in immediately after making the mixture; therefore, in order to aſcertain the firſt temperature of the mixture, take its temperature at ſtated times, viz. after 15 ſeconds, and again after 30 ſeconds; then ſay, as the ſecond temperature is to the firſt, ſo is the firſt to the real temperature at the time of making the mixture.

more of mercury at 50°, the temperature of the mixture will be 52°. (viz. $\frac{2\times 40^\circ+4\times 60^\circ+4\times 50^\circ}{2+4+4}$)

The foundation of the rule is very evident; for ſince heat or caloric expands equably amongſt homogeneous bodies that are in contact; it follows that the temperature of the mixture muſt be a mean of the ſeparate temperatures of the parcels, and this rule does only aſcertain that mean; for the ſum of all the degrees of heat is divided by the ſum of the weights of all the parcels. See page 231. vol. II.

When bodies of different ſort of matter are placed in a higher temperature, or, in other words, when heat is communicated to bodies of different nature, but of the ſame weight and equally expoſed, it has been found that ſome of them abſorb, or combine with, a greater quantity of caloric than others; hence the former are ſaid to have a greater *capacity* for caloric than the latter; and the proportional quantity of caloric which each body abſorbs, is called the *ſpecific caloric* of that body [*]. Each particular body, as far as has been tried, has been found to have a particular capacity for caloric. Thus, if a pound of mercury, and a pound of another metal, be placed in a higher temperature, and it be

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[*] For if a body A can abſorb, for inſtance, 3 times as much caloric as B; it is evident that, in a natural ſtate, A contains 3 times as much caloric as B, when both appear of the ſame temperature.

found that the other metal abſorbs twice as much caloric as the mercury; then the ſpecific caloric of that other metal is to the ſpecific caloric of mercury, as two to one.

This proportional quantity of caloric, which one body abſorbs more or leſs than another body, has alſo been called *latent heat*; but the expreſſion is evidently improper; for though one body A has, for inſtance, twice as much caloric as another body B of equal weight, yet A has a double capacity, or has an affinity for caloric as ſtrong again as B; in conſequence of which the caloric is detained with equal power; nor can it be communicated from A to B; in which caſe only it would act as heat, viz. it would expand B, or if B be a living animal, would excite in it the ſenſation of heat.

It is now neceſſary to ſhew by what means the ſpecific caloric of bodies is to be aſcertained. For this purpoſe,

Take two bodies of equal weights, and whoſe capacities are permanent; for inſtance, A *and* B, *one of which at leaſt is a fluid; let them acquire different temperatures, and aſcertain thoſe temperatures by the thermometer. Then put the ſolid into the fluid, or mix the two fluids together very expeditiouſly, and immediately after place the thermometer in the mixture, and aſcertain its temperature. Now the ſpecific caloric of the body* A *is to the ſpecific caloric of the body* B, *as the difference between the temperature of* B *previous to the mixture, and the temperature of the mixture, is to the difference* *between the temperature of* A *previous to the mixture and the temperature of the mixture (obſerve the precautions of the note in page* 65.) For inſtance,

Temperature of A - -	110°	
Temperature of the mixture	80°	30° the difference.
Temperature of B - -	40°	40° the difference.

Therefore the ſpecific caloric of A is to the ſpecific caloric of B, as 40 to 30; or as 4 to 3.

If the ſame two bodies be heated differently, the reſult will give preciſely the ſame proportion of differences, and of courſe the ſame proportion of ſpecific calorics. Thus,

Temperature of A - -	40°	
Temperature of the mixture	70°	30° the difference.
Temperature of B - -	110°	40° the difference.

It is evident that if the two bodies had had equal degrees of affinity, or had had equal capacities for caloric; (both thoſe expreſſions meaning the unknown cauſe of the ſame perceivable effect) the temperature of the mixture would have been 75°, viz. an arithmetical mean between the temperatures of A and B; ſo that, in the firſt example, A would have loſt 35°, and B would have acquired 35° of heat. But, ſince the temperature of the mixture was 80°, it appears that the 70 degrees of heat, which A had more than B, muſt have been diſtributed ſo as to increaſe the temperature of B by 40°, and to leſſen the temperature of A by 30°. Now, when a quantity of heat is communicated to a body, that portion of it, which is abſorbed by the body, does not raiſe its temperature, or is that portion which, added to the increment of temperature, becomes equal to the original quantity of heat; for inſtance, if 10° of heat be communicated to a body, and the temperature of that body is thereby raiſed 4°, it is evident that ſix degrees of heat have been abſorbed, &c. therefore, in the above-mentioned caſe, the portion of caloric abſorbed by B, muſt have amounted to 30°, ſince its temperature was raiſed 40°, and the quantity retained by A muſt have amounted to 40°, ſince its temperature was leſſened 30°.

The ſame reaſoning, *mutatis mutandis*, may be applied to the ſecond caſe, and in general to all ſuch like caſes.

By this means the ſpecific caloric of various ſubſtances have been determined with as much preciſion as the difficulty of performing ſuch experiments, eſpecially with elaſtic fluids, and the fluctuating quality of the articles, will admit of.

In the following liſt, the ſpecific caloric of water is called one, or unity, and that of every other ſubſtance is expreſſed in proportion to this unity; for inſtance, the ſpecific caloric of ſpermaceti oil is 0,500, viz. the half of that of water; 5-tenths being the half of a unit; which means that a quantity of ſpermaceti oil can abſorb the half of that quantity of caloric which an equal quantity of water can abſorb in ſimilar circumſtances. Alſo the

the ſpecific caloric of the ruſt of iron is 0,250, viz. a quarter of that of water; which means that in equal circumſtances the ruſt of iron will abſorb $\frac{1}{4}$ of that quantity which an equal weight of water can abſorb; and ſo of the reſt *.

Table of the ſpecific Caloric of different Bodies.

		Specific Caloric.
Hydrogan gas, C		21,400
Oxygen air	C	4,749
	K	87,000
Atmoſpherical air	C	1,790
	K	18,670
Carbonated ammonia, or mild volatile alkali, K		1,851
Aqueous vapour †, C		1,550

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* This table has been collected from the experiments of the principal labourers in this field of curious inquiry. To each article the initial of the name of the gentleman by whom it was determined, is ſubjoined, viz. C, for Crawford; K, for Kirwan; and L, for Lavoiſier and Laplace, conjointly.

† The ſpecific caloric of water in the ſtate of vapour is ſuppoſed, by Mr. Pictet, to be about 8 $\frac{1}{2}$ times greater than that of the ſame water in a boiling ſtate. But the volume of the vapour (he ſuppoſes) is about 1800 times greater than that of boiling water. There is therefore 212 times more caloric in any given volume of boiling water, than in an equal volume of vapour. Phil, Mag. vol. VI. p. 244. Other perſons have reckoned it much higher, and others lower. In ſhort, the ſpecific caloric of ſteam is not yet known with ſufficient certainty.

Solution

	Specific gravity.
Solution of brown ſugar, K - - -	1,086
Carbonic acid { C - - - - - -	1,045
Carbonic acid { K - - - - -	0,270
Arterial blood, C - - - - - -	1,030
Water - - - - - - - - - -	1,000
Freſh cow-milk, C - - - - -	0,999
Sulphuret of ammoniac, ſpecific gravity, 2,818, K - - - - - - -	0,994
Ice, or congealed water, K - - -	0,900
Venous blood, C - - r - - -	0,893
Solution of Epſom ſalt. or ſulphate of magneſia, ſalt 1, water 2, K - -	0,844
Solution of common ſalt, or muriated ſoda, ſalt 1, water 8, K - - - -	0,832
Solution of ſal ammoniac, or muriate of ammoniac, ſalt 10, water 15, K -	0,798
Azotic gas, C - - - - - - - -	0,794
Hide of an ox, with the hair on, C -	0,787
Lungs of a ſheep, C - - - - -	0,769
Solution of cream of tartar, cream 10, water 2373, K - - - - - - -	0,765
Solution of pot-aſh of the ſpecific gravity 1,346, K - - - - - - -	0,759
Sulphuric acid { of the ſpecific gravity 1,885 K - - -	0,758
Sulphuric acid { — — — C	0,429
Sulphuric acid { brown of the ſpecific gravity 1,872, K	0,429
Lean of the beef of an ox, C - - -	0,740
Solution of green vitriol, or ſulphat of iron, ſalt 10, water 25, K - - -	0,734

		Specific caloric.
Solution of Glauber ſalt, or ſulphat of ſoda, ſalt 10, water 29, K		0,728
Olive oil, K		0,710
Ammoniac, or cauſtic volatile alkali, K		0,708
Nitric acid	L	0,661
	K	0,844
	Red and ſmoking, ſpecific gravity 1,355, K	0,576
Muriatic acid, ſmoking, ſpecific gravity 1,122, K		0,680
Solution of alum, ſalt 100, water 445, K		0,649
Solution of nitre, ſalt 1, water 8, K		0,646
Alcohol	C	0,602
	of the ſpec. gravity 0,783, K	1,086
Linſeed oil, K		0,528
Rice, C		0,506
Horſe-beans, C		0,502
Spermaceti oil	C	0,500
	K	0,399
Oil of turpentine, K		0,472
Wine vinegar, K	ſtrong	0,387
	diſtilled	0,103
Ruſt of iron	C	0,250
	K	0,320
Pit-coal, C		0,278
Charcoal, C		0,263
Chalk, C		0,256
Waſhed diaphoretic antimony	C	0,227
	K	0,220
Quick-lime	C	0,223
	K	0,217
Oxide of copper		0,227

Baked

	Specific caloric.
Baked earth, K	0,195
Cryſtal, L	0,193
Cinders of coals, C	0,192
Aſhes of cinders, C	0,185
Flint glaſs, K	0,174
Ruſt of iron, nearly freed from air, C	0,167
Waſhed diaphoretic antimony, nearly freed from air, C	0,167
Aſhes of the elm tree, C	0,140
Oxide of zinc nearly freed from air, C	0,137
Iron C	0,127
K	0,125
L	0,101
Braſs, C	0,112
Copper, C	0,111
Oxide of a mixture of lead and tin, K	0,102
White oxide of tin, nearly freed from air, C	0,099
Zinc, C	0,094
Aſhes of charcoal, C	0,091
Tin C	0,070
K	0,068
Yellow oxide of lead, nearly freed from air, C	0,068
Antimony in the metallic or reguline ſtate C	0,064
K	0,086
Lead C	0,035
K	0,050
Mercury L	0,029
of the ſpecific gravity 13,3, K	0,033

The capacities of bodies for caloric are pretty permanent, as long as the bodies remain in the ſame ſtate with reſpect to conſiſtency.

Almoſt all bodies in nature have been found capable of exiſting in three different ſtates, viz. the ſolid, the liquid, and the aëriform, vaporous, or elaſtic ſtate of fluidity. In each of thoſe ſtates the capacity of the body for caloric, or its ſpecific caloric, is different from what it is in the other ſtates. It is leaſt in the ſolid and greateſt in the ſtate of elaſtic fluid.

If more caloric be communicated to a ſolid body than what its capacity will bear, and if that exceſs of caloric be equivalent to the capacity of that body when in a liquid ſtate; then that ſolid will be liquified by it. The ſame thing muſt be underſtood of the converſion of a liquid into the aëriform ſtate

The reverſe of this propoſition is likewiſe true, viz. if ſo much caloric be abſtracted from a liquid, as to leave in it that quantity only which its capacity when in a ſolid ſtate can hold; then that liquid will be rendered ſolid or congealed. The following example will illuſtrate this theory.

When a piece of ice, of a temperature lower than 32°, is placed in a higher temperature, the temperature of the ice is raiſed as high as 32°, and there it remains; for all the ſurplus of heat is abſorbed by that external quantity of ice which is converted into liquid water. When a quantity of water is placed in a higher temperature, the temperature of the water is gradually raiſed as high as 212°, (under a mean or more uſual preſſure of the atmoſphere) but it cannot be raiſed higher, becauſe all the ſurplus of heat is abſorbed by that quantity of water which is converted into ſteam. On the other hand, when ſteam is converted into water, caloric is ſeparated from it, and when water is converted into ice, caloric is alſo ſeparated from it *.

It has been found, that when water at 172° is mixed with an equal weight of water at 32°, the temperature of the mixture is 102°, agreeably to what has been ſaid above. But when a quantity of water at 172° is mixed with an equal weight of ice or ſnow at 32°, the temperature of the mixture is 32°. Whence it is juſtly inferred, that water in a liquid ſtate contains 140° (viz. 172°

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* If a quantity of water, with a thermometer in it, be placed in a cold or freezing mixture, the water often remains fluid, when the thermometer ſhews, that its temperature is 30° or 28°, or even lower. At laſt it freezes very quickly, eſpecially on giving a little ſtroke or agitation to the veſſel, and at the ſame time the thermometer immediately riſes to 32°, which ſeems to indicate that the water cannot eaſily part with its caloric, even when placed in a lower temperature. The cauſe of that impediment is not known.

minus 32°) of caloric more than when it exiſts in a ſtate of ice *.

In ſhort, it appears that a certain quantity of caloric is indiſpenſably neceſſary to keep a body in a ſtate of vapour or elaſtic fluid, that a ſmaller quantity is indiſpenſably neceſſary to keep it in a liquid ſtate, and that a quantity ſtill ſmaller of caloric exiſts in a ſolid and in any temperature, as low however as a certain limit. This limit, or the point of total privation of caloric, has been deduced by calculation from the preceding reſults, and upon a probable ſuppoſition.

Before we endeavour to explain the nature of that limit, it will be neceſſary to make a few uſeful remarks with reſpect to the formation of the preceding table of the ſpecific caloric of bodies.

The rule for finding the ſpecific caloric of bodies (page 67.) directs to mix bodies, whoſe capacities are *permanent* during the operation; the reaſon of which

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* Owing to the difficulty of performing this experiment, and particularly of aſcertaining the firſt temperature of the mixture, the quantity, or the degrees of caloric which fluid water contains more than an equal quantity of ice, has been ſtated differently by different authors. Dr. Crawford reckons it 172°. Dr. Leſlie ſays to have been found by Dr. Black, equal to 147°. Lavoiſier reckons it 167°. Profeſſor Wilcke found it equal to 130°. Bergman found it equal to 129°,6, viz. almoſt the ſame as Wilcke. In ſome books I find it ſtated at 162°, in others at 140°.

which is, that when bodies have their capacities altered by a change of form, the temperature of the mixture muſt vary according to that unknown change of capacity, &c. Therefore the proportion between the ſpecific caloric of water and of ice, cannot be determined by mixing equal quantities of water and pounded ice or ſnow. But it may be determined by employing a third ſubſtance, viz. by determining in the firſt place, the proportion between the ſpecific caloric of that other ſubſtance and ice, in a temperature lower than 32°, and making the ſpecific caloric of the other ſubſtance 1. Secondly, by determining the proportion between the ſpecific caloric of that other ſubſtance and water in a temperature higher than 32°, ſtill reckoning the ſpecific caloric of the other ſubſtance 1; and laſtly, by comparing the ſpecific caloric of water with that of ice*.

When

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* Thus one pound of ice, at - - 32°
2 difference.
Temperature of the mixture - 30°
8 difference.
Diaphoretic antimony, one pound, at 22°

This firſt operation ſhews, that the ſpecific caloric of ice is to that of diaphoretic antimony, as 8 to 2, or 4 to 1.

Alſo one pound of water, at - 162°,5
22,5 difference.
Temperature of the mixture - - 140°
100 difference.
One pound of diaphoretic antimony at 40°

This

When in ſuch experiments a fluid ſubſtance can be uſed with a ſolid, the operation is undoubtedly preferable to the uſe of two ſolids; yet in certain caſes powders, or comminuted ſolids, give a tolerably uſeful reſult.

Experiments of this nature with aërial fluids are extremely difficult, principally owing to the ſmall weight of thoſe fluids, and to the difficulty of mixing them with ſufficient expedition. The operation likewiſe requires particular inſtruments*.

The total privation of caloric, or the loweſt degree to which a thermometer with Fahrenheit's ſcale would deſcend, if it were ſituated in a place totally deſtitute of caloric, has been deduced from the above-mentioned proportion between the ſpecific caloric of water and that of ice, and from the known quantity of caloric which water at 32° contains more than ice at 32°. The ſame thing might be deduced from the ſpecific caloric of any other ſubſtance in its two ſtates of exiſtence, &c.

For ſince the quantity of caloric which water contains more than ice, is 140°, and ſince the capacity of water is to that of ice as 10 to 9, it follows

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This ſecond operation ſhews, that the ſpecific caloric of diaphoretic antimony is to that of water as 22,5 to 100; or as 1 to 4,4444, &c. Therefore the ſpecific caloric of water is to that of ice as 4,444, &c. to 4; or as 10 to 9.

* See Dr. Crawford's Experiments and Obſervations on Animal Heat, the ſecond edition.

that 140° is the difference between all the caloric contained in ice, and all that which is contained in water, when both are at the temperature of 32°. Alſo, that this quantity is one-tenth part of the whole caloric which is contained in water when the temperature of that fluid is 32°. Therefore the whole quantity of caloric is 10 times 140°, or 1400° *, viz. 1368° below 0 of Fahrenheit's ſcale; ſo that in a place totally deſtitute of caloric, that thermometer would deſcend to —1368°, provided the fluid of that inſtrument were capable of it †.

The ſuppoſition upon which this determination is eſtabliſhed, is that the capacity of ice is permanent at any temperature below 32°.

Meſſieurs Lavoiſier and Laplace contrived a different method of determining the ſpecific caloric of bodies. According to their method, a body heated

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[*] Let x repreſent the whole quantity of caloric contained in the water; then we have $10 : 9 :: x : 0{,}9x$. By diviſion $10 - 9\ (1) : 9 :: x - 0{,}9x\ (0{,}1x) : 0{,}9x :: 140 : 0{,}9x$. Therefore, $9 \times 140 = 1 \times 0{,}9x$; and $x = \frac{1260}{0{,}9} = 1400$.

[†] If the quantity of caloric which water at 32° contains more than ice at 32°, be reckoned, not 140°, but, according to Bergman, 129°,6, then the loweſt degree of the thermometer, or the total privation of caloric, would bring the thermometer down to (1296° — 32° =) — 1264°. A ſuitable alteration muſt be made according to other eſtimates. See the note in page 76.

to a certain degree is placed contiguous to a quantity of ice, and its ſpecific caloric is determined by the quantity of ice which that body is capable of melting. Thus, if of two bodies, A and B, of equal weight and equally heated, placed ſucceſſively in a certain quantity of ice, A be found to have melted three times as much ice as B, then the ſpecific caloric of A will be to the ſpecific caloric of B, as 3 to 1.

For this purpoſe the above-mentioned gentlemen contrived an apparatus, which they called the *calorimeter*, and of which, fig. 11. Plate XVIII. exhibits a ſection. It conſiſts of a veſſel ſtanding on three legs, of which two are ſeen in the figure, and having three diviſions, viz. an interior one *ffff*, which is formed of iron wire, a middle diviſion *bbbb*, and an external one *aaaa*. The body ſubjected to experiment is placed within the wire diviſion *ffff*, and this diviſion is covered with a particular cover HG. The other two diviſions and the cover HG are filled with ice, and a large cover alſo filled with ice goes over the whole inſtrument, its edge being fitted to the external grove of the inſtrument. The ice of the external diviſion ſerves to protect the ice of the middle diviſion from the heat of the atmoſphere; hence the ice of the middle diviſion can only be melted by the heat of the body, which is placed in the wire diviſion. The water of the ice thus melted, paſſes through the grate *m m*, and through a ſtrainer placed a little below; then comes

out

out of the tube *dx*, and is received in a veſſel placed under it. This is the quantity of water which indicates the ſpecific caloric of the body under trial. The tube T*s*, with the ſtop-cock *r*, ſerves to drain the water from the ice in the external diviſion *.

If it be required to determine the ſpecific caloric of a ſolid body, its temperature muſt be raiſed; for example, to 212°; it muſt then be placed into the calorimeter, and ſuffered to remain there till its temperature be reduced to 32°. Then by weighing the water which has flowed out of the tube *dx*, the quantity of ice diſſolved during the cooling may be determined. According to Lavoiſier's determination, one pound of water at 167°, will diſſolve a pound of ice; therefore, to determine the ſpecific caloric of the body, the quantity of ice diſſolved muſt be divided by the product of the weight of the body (expreſſed in pounds and decimals) multiplied by the number of degrees above 32°, to which that body has been raiſed previous to the experiment. The quotient indicates the quantity of ice which a pound of that body can diſſolve in cooling 1°. If this quotient be multiplied by 167°, the product will ſhew the quantity of ice which a pound of that body heated to 167°, can diſſolve in cooling down to 32°. This will be the value of its ſpecific caloric.

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* For a more particular deſcription of this apparatus, ſee Lavoiſier's Elements of Chemiſtry, Part III. Chap. III.

Otherwiſe,

Otherwiſe, having the original temperature of the body, and the quantity of ice melted by the ſame, ſay, as that temperature is to that quantity of ice, ſo is 167°, to a fourth proportional, viz. to the quantity of ice which would have been melted if the original temperature of the body had been 167°. Laſtly, the above-mentioned fourth proportional muſt be divided by the weight of the body (expreſſed in pounds and decimals) and the quotient will expreſs how much ice one pound of that body can diſſolve. This is the value of its ſpecific caloric.

"If the body be a fluid, it muſt be put into ſome veſſel, the ſpecific caloric of which has been previouſly determined. The proceſs is the ſame as that deſcribed in the preceding two paragraphs; but care muſt be taken to deduct from the quantity of ice diſſolved, that which ariſes from the cooling of the veſſel.

"If the quantity of caloric which diſengages itſelf from the combination of ſeveral ſubſtances be required, they muſt be all reduced to the temperature of 32°, they are then to be mixed together in the interior part of the calorimeter, and to be left there till they return to the term 32°. The quantity of ice diſſolved will indicate the quantity of caloric diſengaged during the combination.

"When bodies in a ſtate of combuſtion, or living animals, are ſubjected to trial, the operation is the ſame; except that freſh air muſt be introduced into the

the calorimeter; that this air, when it arrives, ſhall be at the temperature of 32°; and that it be at the ſame when it iſſues from it, in order to avoid error in the reſult: for this purpoſe, when it enters and iſſues from the veſſel, it muſt be made to paſs through tubes ſurrounded with pounded ice."

By means of the calorimeter, Meſſieurs Lavoiſier and Laplace determined the ſpecific caloric of ſeveral ſubſtances, of which mention has been made in the table of page 70, and to which the following three curious reſults will be added *.

The combuſtion of one pound of phoſphorus requires 1½ pound, or 27648 cubic inches, of oxygen gas, and forms 2 ½ pounds of concrete phoſphoric acid. The caloric diſengaged in this combuſtion and furniſhed by the oxygen gas, cauſes 100 pounds of ice to diſſolve, and conſequently excites 13532° of heat. Hence it reſults that one cubic foot of oxygen air can furniſh caloric enough to excite above 876° of heat, and of diſſolving 6,25 pounds of ice.

The combuſtion of one pound, or 249081 cubic inches of hydrogen gas, requires 104448 cubic inches of oxygen air, diſſolves 295,6 pounds of ice, and forms 61440 grains of water; which ſhews that ſome caloric remains in the water; for otherwiſe that quantity of oxygen air would melt more ice.

The combuſtion of one pound of charcoal required 47396 cubic inches of oxygen air, diſſolved 96 ½

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* Lavoiſier's Chemiſtry, Part III. Chap. III.

pounds of ice, and formed 47358 cubic inches of carbonic acid gas, which weighed 32914 grains. This alſo ſhews that a conſiderable quantity of caloric enters into combination with, or is employed to form, the carbonic acid gas.

I ſhall juſt obſerve, with reſpect to the calorimeter, that notwithſtanding its great utility, yet both its conſtruction and its uſe are not free from objections.

In concluſion it ſeems, as all the facts tend to prove, that caloric is a real ſubſtance, perhaps the only real fluid and the general ſolvent of all other bodies; for any other body, as far as we are able to try, becomes a fluid by combining with a ſufficient quantity of caloric.

It enters into combination or mixes with the particles of all bodies, and produces the effects which other combinations are wont to produce, viz. it enlarges their bulk; is expelled by compreſſion; it ſeparates other ſubſtances which have leſs affinity than caloric for a given body, and diminiſhes their attraction of aggregation; it mixes in greater quantities with ſome bodies than with others; and it paſſes through ſome bodies eaſier than through others. When caloric is expelled from a chemical combination, the bulk of the mixture is leſs than that of the ſum of the ingredients; and, on the contrary, when the compound is greater in bulk than the ſum of the ingredients, cold is produced, viz. caloric is abſorbed, and of courſe is ſeparated from the contiguous bodies.

bodies. All this ſhews that caloric has bulk like other matter.

The heating, or the addition of heat to a body, has not been found to increaſe its weight*. Then if caloric be matter, it will naturally be aſked, why does it not poſſeſs weight or gravity like other matter? In anſwer to this queſtion, Mr. Tillock ingeniouſly obſerves, that the ſpecific gravity of bodies is diminiſhed by heating, viz. by the communication of caloric, ſince they are increaſed in bulk; and that the addition of heat to a body in air produces the ſame effect that a piece of cork would do if it were annexed to a piece of gold in water, viz. leſſen its gravity, becauſe cork, though poſſeſſed of gravity, is lighter than water; and caloric may likewiſe be poſſeſſed of gravity, though it be lighter than air. He imagines that if the experiment were performed in vacuo, the increaſe of abſolute weight by the addition of heat to a given body, might be perceived†.

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[*] See Count Rumford's Paper on the weight aſcribed to heat, in the Philoſophical Tranſactions for 1799.

[†] Philoſophical Magazine, N° XXXIV.

CHAPTER IV.

OF THE PRODUCTION, COMMUNICATION, AND APPLICATION OF HEAT AND COLD.

HAVING treated ſufficiently of the theory of heat in the preceding chapters, it is now neceſſary to examine the ſubject in a manner more popular and more generally uſeful.

Heat and cold are relative terms. The ſame temperature is cold with reſpect to a higher temperature, and hot with reſpect to a lower temperature. But in common language the more uſual, or the mean temperature of the country, is conſidered as the limit of heat and cold; below that limit we uſually call it cold; above that limit we call it hot.

The mean temperature of the ſame country is ſubject to a very trifling variation from year to year; but the mean temperature of different countries differs conſiderably; nor is that difference proportional merely to the latitude of the country. It depends alſo upon the ſituation of the land or the water, upon the vicinity of large continents, high mountains, or woods, or extenſive ſeas, &c.

All the heat we experience in the world is derived from three ſources, viz. 1ſt, from the ſun; 2dly, from compreſſion, under which denomination we compriſe colliſion and friction; and 3dly, from the decompoſition and compoſition of bodies, which comprehends combuſtions, fermentations, &c.

I. The direct rays of the ſun on the ſame ſpot of the ſurface of the earth are more or leſs hot according to the time of the year, clearneſs of the atmoſphere, ſtate of the wind, and the color, together with the quality of the ſpot. On this iſland, and in the hotteſt time of the ſummer, the direct rays of the ſun ſeldom raiſe the thermometer ſo high as 110°. In other climates, eſpecially within the tropics, they raiſe the thermometer conſiderably higher, viz. 20, or 30, or, as it is ſaid, even 40 degrees higher than 110. But we muſt not believe the idle ſtories of their melting lead, or even of their ſetting fire to gunpowder.

It is not on account of the ſun's being nearer or farther from us, that we receive much more heat at one time of the year than at another; for the difference of its diſtance is too ſmall to produce any ſenſible effect: but we receive more heat in ſummer than in winter, 1ſt, becauſe the ſun is nearer to our vertex, or to the zenith, and its rays paſs a ſhorter way through the atmoſphere, and are of courſe intercepted by it leſs than in winter. See fig. 12. Plate XVIII. where AB repreſents the ſurface of the earth, FGH the atmoſphere, D and E two

two ſituations of the ſun, and C a particular ſpot on the ſurface of the earth. It is evident that HC is greater than GC, viz. that the rays of the ſun paſs through a ſmaller part of the atmoſphere, when the ſun is at D than when it is at E. This alſo ſhews why the rays of the ſun are, upon the whole, hotter at about noon than when the ſun is juſt riſen or near ſetting: 2dly, we receive more heat when the ſun is higher, becauſe then a greater quantity of its rays fall upon any given portion of the ſurface of the earth, than when the ſun is lower and its rays come in a more oblique direction: and 3dly, becauſe in the ſummer the ſun remains longer above the horizon than in winter, and of courſe the ſurface of the earth is expoſed longer to its rays.

It might at firſt ſight be expected, that in general the hotteſt time of the day would be at noon, viz. when the ſun is higheſt; and that the hotteſt time of the year would be when the ſun is at the ſummer ſolſtice. But this is not the caſe; for the hotteſt part of the day, when no accidental circumſtance intervenes, is always ſome time in the afternoon, and nearer to the noon in winter than in ſummer. In the laſt-mentioned ſeaſon, in this climate, the hotteſt time of the day (I mean not of the direct rays of the ſun, but of the air in the ſhade) is at about 2 o'clock, or rather a little before. The hotteſt time of the year in this country generally is in July, viz. after the ſolſtice. The reaſon of this is, that though the rays of the ſun give more heat when the ſun is higher, and of courſe at 2 o'clock they muſt give leſs heat than at noon; yet the earth, and the air contiguous to it, are hotter at two, becauſe they retain a conſiderable portion of the heat acquired before that time; ſo that as long as they acquire at any particular time a greater quantity of heat than they loſe of what they had previouſly acquired, their temperature muſt continue to increaſe. The ſame thing, *mutatis mutandis*, muſt be underſtood with reſpect to the communication of cold, or privation of heat.

The earth acquires heat in the day-time, and loſes it during the night. In ſummer the loſs of heat during the night is leſs than the acquiſition of it during the day; therefore that exceſs of heat is gradually communicated from the ſurface to the more internal parts of the earth. In winter the loſs of heat during the night is greater than the acquiſition of it during the day; therefore cold is gradually communicated from the ſurface to the more internal parts of the earth. But when the above-mentioned ſummer heat has penetrated a certain way, the winter cold begins to counteract it; and when the cold has penetrated a certain way, the next ſummer heat begins again to counteract it; ſo that below that certain depth, there is no alteration of temperature at any time of the year; unleſs you come in the vicinity of ſome volcano, or near any particular combination of fermenting minerals; which ſpots, however, in proportion to the reſt of the outer part

part of the earth, are exceedingly few, and very limited in their influence.

This is the reaſon why in deep pits, and even within 50 or 60 feet of the ſurface of the earth, the thermometer makes little or no variation throughout the year. Thoſe pits ſeem to us warm in winter and cool in ſummer; for as they remain always at the ſame temperature, that temperature is in fact warmer than that of the external air in winter, and cooler in ſummer. This likewiſe ſhews why the waters of deep wells ſeem cool in ſummer and warm in winter. Indeed ſo nearly uniform is their temperature, that we may from them aſcertain the mean temperature of a country; viz. draw a pail of water out of a deep well (for inſtance, of above 50 feet) eſpecially a well that does not contain much water, and immediately place the thermometer in it; the degree to which that thermometer is raiſed, is the mean temperature of that country wherein the experiment is performed, or it differs very little from it[*].

In the cave of the Obſervatory at Paris, about 90 feet below the ſurface of the ground, the thermometer ſtands at 55°[†], its variations not amounting to one degree. The mean of the greateſt colds and

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[*] See the Philoſophical Tranſactions, vol. 78, p. 110.

[†] Dr. Martine ſays 53°. See his Eſſays, Medical and Philoſophical, p. 319.

and the greateſt heats obſerved at Paris during 56 years, is 54°,5[*].

In London the mean temperature is 50°.[†] But in proceſs of time the mean temperature of a country is liable to changes, owing to cultivation and to a variety of other cauſes. See Mann's Papers, Phil. Mag. vol. IV. and V.

The following general axioms have been formed by L. Cotte, reſpecting the thermometer, from an examination of various meteorological obſervations made during 30 years [§].

" The thermometer riſes to its extreme height oftener in the temperate zones, than in the torrid zone.

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[*] Mem. de l Acad. des Sciences, 1765, p. 202.

[†] It appears from the Journal of the Royal Society, which ſtates two obſervations of the thermometer for every day throughout the year, that the general mean is 50°,5; the mean for each ſingle year being ſometimes as low as about 48°, and at other times as high as about 52°. But, as it appears from the regiſter of Six's thermometer, which has of late years been inſerted in the Journal of the Royal Society, the mean between the greateſt colds of the night, and the greateſt heats of the day, is 49,97; and from the obſervations made in Marlborough-ſtreet, by the late Lord Charles Cavendiſh, the mean between the greateſt heats of the day, and the greateſt colds of the night, is 49°,196.

See the Philoſophical Tranſactions for 1788, Art. V. and VI. alſo Kirwan on the temperature of different latitudes.

[§] Gren's Journal de Phyſ. vol. III. p. 5.

" It changes very little between the tropics; its variations, like thoſe of the barometer, are greater the more one proceeds from the equator towards the poles.

" It riſes higher on the plains than on mountains.

" It does not fall ſo much in the neighbourhood of the ſea as in inland parts.

" The wind has no influence on its motions.

" Moiſture has a peculiar influence on it, if followed by a wind, which diſſipates it.

" The greateſt heat, and the greateſt cold, take place about ſix weeks after the northern or ſouthern ſolſtice.

" The thermometer changes more in ſummer than in winter.

" The coldeſt period of the day is before ſunriſe.

" The greateſt heat in the ſun and the ſhade ſeldom takes place on the ſame day.

" The heat decreaſes with far more rapidity from September and October, than it is increaſed from July to September.

" It is not true, that a very cold winter is the prognoſtic of a very hot ſummer."

The ſituation of the thermometer, for aſcertaining the temperature of the ambient air at different times, is not a matter of indifference. That it ſhould be placed out of the houſe, at a little diſtance from the wall of the houſe, and where no ſtream of hot

hot air from kitchens, &c. may affect it, is clear and obvious; but there have been obſerved certain peculiarities of local heat, which often render the indications of a ſingle thermometer, doubtful or equivocal; hence the ſureſt method would be to employ two or three thermometers ſituated at different heights from the ſurface of the earth, and to take a mean of their contemporaneous indications.

In ſhort, it has been obſerved that thermometers, ſituated at different altitudes, are differently affected; and, what is more remarkable, that in the night time, eſpecially when the air is ſtill, and the ſky perfectly free from clouds, the thermometer, cloſe to the ſurface of the earth, indicates a greater degree of cold than at a higher ſituation. A conſiderable number of obſervations have been made with reſpect to this peculiarity of temperatures; but they do not as yet enable us to form any general laws. It can only be ſaid, that this difference of partial temperatures, which does not amount to many degrees, may be owing to evaporation; and perhaps, as Mr. Six conjectures, to the coolneſs which the dews or vapours may acquire in their deſcent *.

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* See Mr. Wilſon's Paper in the Philoſophical Tranſactions for 1780, and Mr. Six's curious papers on Local Heat, in the Philoſophical Tranſactions for 1784 and 1788.

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This however muſt be underſtood of no great altitudes; for on great elevations, ſuch as mountains, the difference of temperature is very remarkable; ſuch indeed, that in every climate, even in the torrid zone, there are mountains which, beyond a certain altitude, are covered with everlaſting ice; owing to their being ſo far from the body of the earth, as not to participate of the general ſtock of heat which the whole body of the earth receives from the ſun. Another concurring cauſe is, that mountains are greatly expoſed to winds, eſpecially to thoſe which riſe from the plains below, and which muſt occaſion a conſiderable refrigeration, in conſequence, as Dr. Darwin juſtly obſerves, of the expanſion of the aſcending air *.

The line of congelation, beyond which no fluid water is to be found, is more or leſs diſtant from the plane ſurface of the earth, according to the difference of latitude.

It appears from the obſervations of Mr. Bougner and others, that in the middle of the torrid zone the line of congelation lies at about the height of 15600 feet; and near the tropics, or the entrance to the temperate zones, it lies at the height of about 13428 feet. On the iſland of Teneriffe, in lat. 28° north, the line of congelation is at the altitude of about 10000 feet. It is about 6740 feet high in Auvergne, lat. 45° north. It ſeems to be about

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* Philoſophical Tranſactions for 1788, Art. IV.

5800 in latitudes between 51° and 54° north. In lat. 80° north, lord Mulgrave ſound the line of congelation at the altitude of about 1200 feet above the level of the ſea; whence, as General Roy obſerves, we may conclude, that the ſurface of the earth at the Pole itſelf, is for ever covered with ſnow.

Before we conclude the account of the principal ſource of heat, viz. the ſolar heat, it may be neceſſary juſt to mention, that no ſenſible heat is known to be derived from any other celeſtial body. The moon indeed, on account of the great light it reflects on the earth, might be expected to communicate ſome degree of heat; but though that light, concentrated by a large concave mirror, has been thrown upon the moſt ſenſible thermometers, yet I am not certain that it ever affected them. A great many calculations have been made concerning the proportion between the light which we receive directly from the ſun, and that which is reflected to us from the moon; from which it appears that the latter is ſeveral hundred times leſs denſe than the former; and the heat of both is ſuppoſed to be in the ſame proportion.

II. Compreſſion, or colliſion (which is a ſudden compreſſion) is the ſecond, and the more generally uſed, ſource of heat, and the communication of the heat thus produced to combuſtible matters, produces that decompoſition which is commonly called *fire*.

Wood rubbed againſt wood, or againſt any hard body; metal rubbed againſt metal, or againſt any other body; in ſhort, ſolid bodies rubbed or knocked againſt each other, are thereby heated, often ſo far as to become red-hot.

By this means heat may be produced where there is no oxygen air whatever, ſo that in thoſe caſes it cannot be derived from the decompoſition of that air. This has made ſeveral perſons ſuſpect that heat is not the effect of a peculiar ſubſtance called caloric, but that it is only a peculiar movement of the particles of bodies. It muſt however be conſidered, that there is no friction which does not produce compreſſion, viz. a contraction of the bulk of the bodies concerned, at leaſt for a time*; and therefore that the caloric is forced out of the bodies themſelves, and being communicated to the ſurrounding bodies, produces the uſual ſigns of heat.

What very much corroborates this aſſertion is, that ſubſtances which are not compreſſible, are not heated by mechanical force; thus a flint will only be broken, but a piece of ſoft metal will be heated, by the ſtrokes of a hammer. Thus alſo you may place any weight upon a quantity of water, without altering its temperature, becauſe the compreſſibility

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* Woods and other ſoft ſubſtances are viſibly contracted by friction. Metallic bodies are alſo contracted by rubbing, rolling, or hammering; for their ſpecific gravities are thereby increaſed.

of water is almoſt nothing; but if you place an additional weight upon a quantity of air, the bulk of that air will be contracted, and its temperature will be raiſed.

By about 15 or 20 ſmart and quick ſtrokes of a hammer on the end of an iron rod of about a quarter of an inch in diameter, placed upon an anvil, an expert blackſmith will render that end of the rod viſibly red hot. But the production of vivid red ſparks from the ſtriking of a piece of ſteel againſt the edge of a flint, is a phenomenon not leſs curious. Thoſe ſparks, if let fall upon a ſheet of paper, will be found to be particles of the ſteel partly oxygenated. They are ſcraped off by the flint, and of courſe compreſſed ſo as to be heated, &c.

III. The third developement of heat ariſes from mixture, from compoſition and from decompoſition of bodies.

Acids on being mixed with water, ſpirit of wine on being mixed with water, and a great variety of other bodies, on being mixed, become more or leſs hot. It is not every mixture that becomes hot; but it has been remarked, that whenever a mixture of two or more bodies is attended with heat, the bulk of that mixture is leſs than the ſum of the bulks of the ſeparate ingredients; viz. a compreſſion or concentration takes place, which is accompanied with a developement of caloric.

Subſtances, whether animal or vegetable, under fermentation, viz. decompoſing ſubſtances, are always attended with heat. That ſort of decompoſition of combuſtible ſubſtances, or of oxygen air, which produces a redneſs, &c. is commonly called fire; and is gradually propagated from one part to another by its own action. Thus, when the abovementioned ignited particles of ſteel are received upon a ſubſtance of eaſy decompoſition, ſuch as tinder, the touching parts of the tinder are heated and decompoſed by that heat, their component particles then, attracting the oxygen of the air, diſengage the caloric of that fluid, and this caloric heats and decompoſes the contiguous particles of the tinder, which alſo decompoſe more air; and thus the combuſtion proceeds and continues as long as there are combuſtible ſubſtances and oxygen air ready for decompoſition.

It is evident that the contact of a ſubſtance actually burning is not abſolutely neceſſary for communicating the combuſtion to other combuſtible bodies; it being only neceſſary to heat thoſe combuſtible bodies to a certain degree; and heat is communicable without the actual contact of the ignited body.

Sometimes combuſtion is communicated from a burning body to another, which is not ſo near as to be heated ſufficiently by it. Thus, when a tallow candle juſt blown out is ſituated within a certain diſtance of the flame of another lighted candle, and in ſuch a direction as that the ſtream of ſmoke or

vapour

vapour, which proceeds from the former, may paſs through the flame of the latter; it frequently happens that the former is thereby lighted. But it muſt be obſerved, that in this and other ſimilar caſes, the ſtream of ſmoke and vapour is a real train of combuſtible matter, which is inflamed, and burns progreſſively from the flame of the lighted candle to the wick of the other.

A variety of œconomical regulations, the eſtabliſhed cuſtoms of the greateſt part of the human ſpecies, the operations of different arts, the comforts and even the actual exiſtence of human life, require an artificial ſupply of heat; and the greateſt part of that heat can only be obtained from the burning of combuſtible bodies.

The combuſtibles, or the fuel for common fires, are either wood or pit-coals; for all the other combuſtible ſubſtances are neither plentiful, nor can they be advantageouſly uſed. Wood for burning is become rather ſcarce almoſt all over Europe; coals are not to be found in every country, and even where found their mines muſt be exhauſted in time. Theſe conſiderations ſuggeſt the propriety of uſing with care and œconomy thoſe two ſpecies of fuel. By proper management a great deal of waſte may be prevented, without diminiſhing the advantages which are derived from the uſe of fires.

In the conſtruction of fire-places, and in the application of their heat, ſome general rules may be of uſe to the intelligent reader.

1. The materials for the conſtruction of fire-places ought to be bad conductors of heat, viz. earthen ware or ſtone, rather than metal; but where metal cannot be avoided, then the metallic parts ought to be ſurrounded by bricks or other bad conductors of heat, excepting where the heat may be required to be tranſmitted.

2. The draught of air neceſſary for the combuſtion ought to be juſt ſufficient, and not too much. The ſtream of it muſt be conveyed in ſuch a direction as not to interfere with the veſſels, or people, &c. that are to be heated by the fire.—It has been found that in a furnace where ſtrong heat is required to be produced, and where bellows are uſed, a large quantity of air thrown in with little velocity, is more uſeful than a ſmaller quantity which is thrown in with greater velocity.

3. When heat is to be conveyed through tubes, paſſages, &c. care muſt be had to ſurround thoſe tubes with bad conductors of heat.

4. In the conſtruction of fire places, furnaces, ovens, &c. and in the management of heat, it muſt be likewiſe remarked, that heat paſſes through certain bodies, is reflected by others, and is refracted (viz. its courſe is bent) in paſſing through others *. Thoſe properties will be briefly explained in the ſequel.

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* For the particular conſtruction of Kitchen fire-places, ſee Count Rumford's Eſſays.

Of the ſolids the metallic ſubſtances are the beſt conductors of heat, next to them are ſome compact ſtones. The other earthy bodies conduct leſs and leſs, in proportion as they are leſs compact in their texture, and more mixed with water or oleaginous ſubſtances. Coals, and other combuſtible minerals, are very bad conductors of heat. Wood, and other vegetable parts, and ſuch bodies as are formed of them, viz. paper, ropes, &c. are ſo bad conductors of heat, that you may ſafely hold a piece of any of them that is actually burning within leſs than an inch diſtance from your fingers. Charcoal and charcoal duſt, are very good non-conductors of heat, and on that account very fit to be placed round tubes, partions, &c. wherein heat is to be retained.

Fluids ſeem to be exceedingly bad conductors, if not perfect non-conductors, of heat. In ſhort, heat ſeems to be propagated through fluids merely in conſequence of the internal motion of their particles. Whatever permits or promotes that motion, contributes to the propagation of heat; — whatever obſtructs that motion, retards the propagation of heat through fluids. The particles of air which come in contact with an heated body, being thereby heated and rarefied, become ſpecifically lighter than the ſurrounding air, and of courſe aſcend; other air then comes in contact with the heated body, and this alſo is heated and cauſed to aſcend, &c. Thus is heat conveyed from the original hot body, by the air, to a diſtance from it; but if that motion of the air be obſtructed, as by the interpoſition of partitions, of papers, wool, cotton, furs, and the like; then that communication of heat is thereby prevented more or leſs, in proportion to the obſtruction to the motion. It is principally on this account that furs, feathers, eider down, cotton, and the like, form warm coverings, viz. becauſe, by preventing in a great meaſure the motion of the air between their filaments, prevent at the ſame time the diſſipation of heat.

The like obſervations are applicable to water, and perhaps to all other fluids. When a veſſel full of water is placed upon the fire, the particles of water that are cloſe to the bottom of the veſſel are firſt heated and rarified, viz. become ſpecifically lighter; hence they aſcend, and other colder particles take their place; theſe are heated next, and likewiſe riſe, &c. This is the cauſe of the inteſtine motion of water whilſt heating. If the fire be applied to the upper part of the water, the lower water will not thereby be heated; for heated and rarefied water will not deſcend.

Count Rumford confined a piece of ice at the bottom of a pretty tall glaſs veſſel full of water near the boiling point, and noted the time it required to melt the ice. He then repeated the experiment, with this difference, viz. that a ſimilar piece of ice was placed on the ſurface of the hot water. It was found that the ice melted more than eight times ſlower

ſlower when boiling hot water ſtood on its ſurface, than when the ice was ſuffered to ſwim on the ſurface of the hot water. This very remarkable phenomenon is eaſily explained on the already mentioned property of fluids; viz. when the ice is ſwimming on the ſurface of the hot water, the particles of the latter that are contiguous to the former being cooled, deſcend, and other hot particles of water take their place, which give to the ice part of their heat and deſcend, and ſo on; but when the ice is at the bottom, the particles of water that firſt come in contact with it, are cooled, and are rendered ſpecifically heavier, in conſequence of which they remain in their place, and no motion will take place within the water *.

AB, fig. 13. Plate XVIII. repreſents a glaſs veſſel, like a thermometer veſſel, but larger, and open at top; the diameter of the cavity of the tube being about a quarter of an inch. Fill ſuch a veſſel with water till within about an inch of the top, and mix with the water ſome powders that may have their ſpecific gravity nearly equal to that of water, ſo as to remain ſuſpended in it (powder of tranſparent yellow amber anſwers very well); for the motion of the water will be rendered manifeſt by the motion of the particles of the powder. If the bulb B be gently heated, a current of warm water will be ſeen to riſe

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* Count Rumford's 7th Eſſay.

along one ſide of the tube, and another current of colder water will be ſeen to deſcend along the other ſide of the tube.

Whatever obſtructs the free motion of the particles of the fluid, does alſo obſtruct the propagation of heat through it. Thus, water thickened by a mixture of ſtarch and other ſubſtances, or impeded in its motion by wool, cotton, eider down, &c. cannot be heated nearly ſo ſoon as clear water. Hence it appears why apples and ſome other fruit are difficultly heated or cooled; namely, becauſe they conſiſt almoſt entirely of minute veſicles full of liquor, conſequently the liquor cannot move from one part of the fruit to the other.

An emanation of heat proceeds from an heated body, when placed in a colder temperature, and expands itſelf in every direction, provided it be not prevented by the interpoſition of particular ſubſtances. Separate parcels of that emanation are called *rays of heat*; not becauſe that emanation (as far as we know) conſiſts of ſeparate ſtreams; but merely for the conveniency of explanation.

The rays of heat are not the ſame thing as the rays of light; for if they were the ſame thing, then a certain quantity of heat ought to be conſtantly accompanied with the ſame quantity of light; whereas we find that ſeveral ſubſtances give out a good deal of light without any ſenſible heat, and others give out a conſiderable degree of heat without any light. But a very ſtrong confirmation of their being

being two ſeparate powers of nature, is afforded by Dr. Herſchel's late diſcoveries, the principal of which will be mentioned in the ſequel.

The rays of heat which come either from the ſun, or from any other hot body, proceed in ſtraight lines all round the body, as long as they do not meet with any oppoſition, viz. any body that hinders their progreſs. When they do meet with any body, then, according to the quality and figure of that body, they are either reflected, viz. turned backwards, or they are abſorbed, or they are tranſmitted through the body. In general, thoſe three effects take place at the ſame time, viz. the rays of heat are partly reflected, partly abſorbed, and partly tranſmitted, by the ſame body; but every body produces ſome one of thoſe effects ſtronger than the others.

The ſame obſervations may be made with reſpect to light, viz. the rays of light do alſo proceed in ſtraight lines from the luminous body in every direction, as long as they do not meet with any body which either reflects, or abſorbs, or tranſmits them. But not all the effects produced by a given body upon the rays of light, are the ſame as thoſe which are produced by the ſame body upon the rays of heat; for inſtance, a plate of metal which is impervious to light, will in great meaſure tranſmit heat; a plate of glaſs will tranſmit light in greater quantity than heat; and ſo forth.

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The ſurfaces of all bodies reflect in greater or leſs quantity the rays of heat which happen to fall upon them. Poliſhed ſurfaces, eſpecially of metallic bodies, reflect them moſt. It has been found that the angle of incidence is equal to that of reflection; or, in other words, the angle which the rays of heat falling upon any point of a given ſurface form with the perpendicular to the ſurface at that point, is equal to the angle which the ſame rays, after reflection, form with the ſame perpendicular; viz. the heat which proceeding from the hot body A, fig. 16. Plate XVIII. paſſes through the hole at G, and impinges at B, upon the reflecting ſurface E F, is reflected in the direction B C, forming the angle of incidence, G B D, with the perpendicular B D, equal to the angle of reflection D B C; and, in fact, the thermometer, ſituated any where in the direction BC, will be affected by the reflected heat.

Hence it follows, that when the reflecting ſurface is not uniform, viz. not poliſhed, but rough and uneven, then the heat is ſcattered in various directions; when the ſurface is flat and poliſhed, the ſtream of reflected heat is equal to the incident ſtream; when the ſurface is convex, the heat is reflected divergingly; and, laſtly, when the ſurface is concave, the heat is reflected convergingly, viz. towards a narrow ſpace, called a *focus*, beyond which the rays of heat having croſſed each other, proceed divergingly. Thus, in fig. 18. Plate XVIII. the heat, which proceeding from the hot body A, falls upon the

the concave reflecting ſurface BC, will be reflected towards EF; viz. the rays which fall upon the part nearer to B, will be reflected in the direction BF, and thoſe which fall upon the part nearer to C will be reflected in the direction CE; ſo that all the rays of reflected heat paſs through a ſmall ſpace or focus at D, where they croſs, and afterwards proceed divergingly towards EF. It is hardly neceſſary to obſerve that the thermometer will be affected more when ſituated at D, than in any other part of the double cone BCDEF. That thoſe rays of heat do actually croſs each other at D, is eaſily proved; for if by interpoſing a ſcreen G, you intercept the upper part of the incident rays of heat, then the thermometer will be affected by the reflected heat only in the direction CE; and if, inſtead of that, you intercept the lower part of the incident rays by means of the ſcreen H, then the thermometer will be affected by the reflected heat only in the direction BF.

The application of reflected heat is pretty well underſtood in œconomical affairs, and may be adapted to a great variety of purpoſes. Thus every body knows the reflecting power of tin plates in what are commonly called Dutch ovens, and in kitchen fire-ſcreens. The reflecting power of the ſides of fire-places, of ovens, of walls in gardens, &c. are likewiſe well known.

The intercepting property, or the abſorption of heat by different bodies, depends upon the colour of of the body, upon its capacity for heat, upon its conducting power, and upon the ſmoothneſs or roughneſs of its ſurface.

Upon the whole, bodies of the darkeſt colour, greateſt capacity for caloric, and rougheſt ſurfaces, abſorb moſt heat. If various thermometers having their bulbs painted each with a different colour, be expoſed to a fire, or to the ſun, or to a lighted candle, they will be unequally affected*.

If equal weights of water, and of mercury, be, *cæteris paribus*, expoſed before a fire, the water will abſorb more heat than the mercury; hence its temperature will be raiſed ſlower than that of the mercury †.

The tranſmiſſion of heat through bodies is alſo attended with remarkable phenomena.

Upon the whole, it ſeems that in paſſing obliquely from a thinner into a thicker medium, the rays of heat are bent towards the perpendicular to the bounding ſurface; and in paſſing from a denſer into a thinner medium, they are bent from that perpendicular. (This bending, in paſſing through, iscalled *refraction)* Thus if a ſtream of heat, proceeding from a body A, fig. 19. Plate XVIII. impinges upon the ſurface CD of a piece of glaſs CEDF, its courſe will be bent into the direction BG, and in going out of the glaſs G,

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* See the Phil. Tranſ. vol. LXX. laſt article.

† See Dr. Martine's Eſſay on the Heating and Cooling of Bodies.

into the air, it will be bent into the direction GI. It follows from this, that according to the figure of the refracting body, the ſtream of heat may be refracted, either irregularly, or in a direction parallel to its incident direction, or in a diverging direction, or, laſtly, in a converging direction; and in the latter caſe the ſmalleſt ſpace into which the refracted rays are collected, (beyond which they proceed divergingly) is called the *focus* of the refracted heat; and a thermometer, ſituated in that place, will be affected more than in any other part of the refracted ſtream.

If the thermometer be placed out of the reflected ſtream, but very near the focus either of reflected or of refracted rays, the temperature of that thermometer will not thereby be raiſed; for the rays of heat do not deviate from their direction as long as they are not oppoſed; but if a piece of wood or metal, or, in ſhort, of any irregular ſubſtance, capable of obſtructing the paſſage of the heat, be placed at the focus, then the above-mentioned thermometer will be affected on the vicinity of that focus; for in that caſe the rays of heat are reflected and ſcattered about. Hence alſo clear water placed at the ſaid focus will be heated either not at all, or a vaſt deal leſs than an opaque body *.

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* The reader muſt not wonder that the reflecting and refracting properties of differently ſhaped bodies, ſuch as concave

The rays of light are likewiſe refracted in going through diaphanous bodies. But it has been clearly proved by Dr. Herſchel, that the rays of heat are refracted differently from the rays of light; ſo that though they are often emitted together, as from the ſun or a common fire, yet they ſeem to be two diſtinct powers.

If the ſun's rays, AB, fig. 15. Plate XVIII. which come into a dark room through a hole at A, be received upon a triangular glaſs priſm C, that ſtream which conſiſts of the rays of heat as well as of the rays of light, will not only be bent by the priſm, but will be likewiſe diſperſed into the oblong figure DF, which is about as broad as the hole at A, and longer or ſhorter in proportion to the diſtance from the priſm; for it may be received upon a table or a ſcreen ſituated at any diſtance from the priſm. This oblong figure conſiſts of light and heat diſpoſed in the following manner. From D to E the figure conſiſts of the luminous rays exhibiting the vivid colours of the rain-bow, with the violet next to D, and the red next to E. The rays which produce the heat are extended from D to F, DF being to DE, as 21 to 12. Thoſe rays of heat

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cave and convex reflectors, lenſes, priſms, &c. are but ſlightly mentioned in this chapter; for they will be particularly deſcribed in the next Section, which treats of light; and where the different ſhapes of bodies are more eſſentially concerned.

cannot be ſeen, but they are manifeſted by the thermometer; for a thermometer placed any where in the extenſion DF, will be affected by the heat; but it will not be affected equally in every part of that oblong figure. The greateſt heat is at g, viz. a little beyond the red light, and where there is no light at all. From that point the heat decreaſes both ways. It appears therefore that the rays of heat are much more extended by their refrangibility than thoſe of light; for we find heat not only with the light from D to E, but alſo from E to F, where there appears no light whatever*.

It is owing to this refrangibility of the rays of heat, that if they be received upon a convex glaſs lens, they will be collected into a narrow ſpace or *focus*, at a certain diſtance from the lens. This focus has all the properties of the focus of reflected rays of heat; which have been conciſely mentioned above. In ſimilar circumſtances the rays of light are alſo collected into a focus; but, owing to the difference between the mean refrangibility of the rays of light and thoſe of heat, the focus of heat is a little farther than the focus of light, from the ſurface of the lens*.

The moſt powerful effects of heat are produced by ſuch a focus of reflected or refracted heat. The burning property of convex lenſes and concave

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* Dr. Herſchel's Paper in the Philoſophical Tranſactions, vol. for 1800, Part III. p. 438.

ſpeculums, are ſo commonly known, that they are generally called *burning glaſſes*. With a double convex lens of not more than an inch in diameter, the heat of the ſun's rays may be collected ſufficiently to ſet fire to tinder, paper, gun-powder, wood, &c. but with large lenſes, or large concave mirrors, and a clear ſun, the moſt refractory metals are ſpeedily fuſed.

Cæteris paribus, the ſhorter is the diſtance of the focus of the lens, or of a ſpeculum, from its ſurface, the more active its power will be. Speculums have been conſtructed within this forty or fifty years, having a focus ſo long as to inflame combuſtibles at the diſtance of 200 feet and upwards *; but we find in hiſtory a few accounts of their having acted at much greater diſtances †.

The moſt powerful burning glaſſes have been made in France and in England. Mr. Trudaine's

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* Buffon, of the French Academy, formed a burning reflector, conſiſting of 168 ſmall plane reflectors, which were diſpoſed in a hollow ſegment of a ſphere, ſo as all to reflect the light and heat of the ſun to the ſame place. With this inſtrument he could fire wood at the diſtance of 209 feet. Burning lenſes have alſo been made of two ſhells of glaſs, like two watch glaſſes, cemented with their edges towards each other in a proper frame, and encloſing ſpirit of wine or water. Globular or nearly globular glaſs decanters, filled with water, are well known to act like burning glaſſes when expoſed to the ſun.

† See Prieſtley's Hiſtory of Viſion, Light and Colours.

lens

lens in France meaſured four feet in diameter. When its focus was ſhortened by the interpoſition of a ſmaller lens, the effect was prodigiouſly great. In about a minute's time it not only melted all ſorts of metallic ſubſtances, but it vitrified earthenware, ſlate, pumice ſtone, aſhes of vegetables, &c. It even melted pitch and other reſinous bodies in water.

Mr. Parker's lens in London, which coſt a great deal of trouble, time, and expence, and which, I am ſorry to ſay, is no longer in this country, was a very extraordinary inſtrument of the kind. It was a double convex lens of flint glaſs, 3 feet in diameter, 3 inches thick in the middle, and weighing 212 pounds. When ſet in its frame, it exhibited a clear ſurface of 32 ½ inches in diameter. Its focal diſtance was 6 feet and 8 inches; but in performing experiments, that focus was generally ſhortened by the interpoſition of a ſecond and much ſmaller lens.

Whilſt it remained in London, this extraordinary burning glaſs was uſed by various ſcientific perſons, for a great number of experiments, the reſults of the principal of which are ſtated in the following table.

Subſtances fuſed by Mr. Parker's lens, with their weights and times of fuſion.

	Weight in grains.	Time in ſeconds.
Gold, pure	20	4
Silver, do.	20	3
Copper, do.	33	20
Platina, do.	10	3
Nickell	16	3
Bar iron, a cube	10	12
Caſt iron, a cube	10	3
Steel, a cube	10	12
Scoria of wrought iron	12	2
Kearſh	10	3
Cauk, or Terra ponderoſa	10	7
A topaz, or cryſolite	3	45
An oriental emerald	2	25
Cryſtal pebble	7	6
White agate	10	30
Flint, oriental	10	30
Rough cornelian	10	75
Jaſper	10	25
Onyx	10	20
Garnet	10	17
White rhomboidal ſpar	10	60
Zeolites	10	23
Rotten ſtone	10	80
Common ſlate	10	2
Aſbeſtos	10	10
Common lime ſtone	10	55
Pumice ſtone	10	24
Lava	10	7
Volcanic clay	10	60
Corniſh Moor ſtone	10	60

The following experiments will ſhew in a moſt convincing manner the reflection of heat, either

quite

quite independent of light, or accompanied with no great quantity of it.

AB and CD, fig. 17. Plate XVIII. repreſent two concave metallic reflectors, about 10 inches, or more, in diameter, and ſituated facing each other at the diſtance of about 15 feet. Suppoſe the focus of AB to be at E, 18 inches diſtant from its ſurface, as alſo the focus of CD to be at F, 18 inches diſtant from the ſurface CD. The operator may be enabled to ſituate the ſpeculums exactly facing each other, by placing a lighted candle in the focus of one of them, and then moving the other until the reflected image of the candle in the focus of this other is found by trial (viz. by receiving it upon a ſmall piece of paper) to fall in the direction of the focus and centre of the firſt ſpeculum *.

Place a piece of iron almoſt red-hot at E, viz. in the focus of the ſpeculum AB; then that part of the heat, which, proceeding from the iron, falls upon the ſurface AB, is reflected by it in a parallel direction to CD, from which it is reflected again

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* I have mentioned the above determinate dimenſions of the reflectors, diſtance, &c. in order to ſhew what will anſwer the purpoſe; but I need hardly add, that with ſmaller or larger ſpeculums, ſet nearer or farther from each other, the effect muſt be proportionately more or leſs apparent. It is not neceſſary that the ſpeculums ſhould have equal ſurfaces, or equal focal diſtances. Speculums of ſilvered braſs, or ſilvered copper, anſwer very well.

convergingly to the focus F; ſo that if the bulb of a thermometer be placed at F, the temperature of that thermometer will be raiſed. If you put a ſheet of paper upon, or in ſhort ſcreen, either of the ſpeculums, the thermometer will deſcend to its uſual temperature. Remove the paper, and the thermometer will riſe again.

If, inſtead of the thermometer, you place a ſmall quantity of gun-powder upon a piece of paper, or upon any other convenient ſtand, at the focus F; and inſtead of the piece of iron, you place a burning charcoal at the other focus E: then, if you render the charcoal vividly red-hot by blowing upon it with a pair of bellows, the gun-powder will be fired off at F by the reflected heat.

If, inſtead of the charcoal and the gun-powder, you ſituate a thermometer at F, and a piece of ice at E, the temperature of the thermometer will thereby be lowered. Cover the ſurface of either reflector, and the thermometer will riſe. Uncover the reflector, and the thermometer will be lowered again, &c.

The reſult of this laſt experiment has been ſuppoſed to militate againſt the commonly received theory of heat, which has been explained in the preceding pages; imagining that the cold which proceeds from the ice is reflected by the ſpeculums to the thermometer, and that, of courſe, cold is ſomething poſitive. But, in my opinion, the true cauſe of the

the phenomenon is, that the heat of the thermometer is reflected upon the ice, in the ſame manner as the heat of the charcoal, in the preceding experiment, is reflected on the gun-powder.

If, inſtead of the thermometer, a burning charcoal be placed at F, no perſon will heſitate to ſay, that the heat of the charcoal is reflected upon the ice; and there is no reaſon whatever for concluding that the ſame thing does not happen when the thermometer is at F.

The heat of a body, ſituated amongſt other bodies, paſſes from the former to the latter, until they all acquire the ſame temperature, and that paſſage is more expeditious in proportion as the difference of temperature is greater. Alſo, if the colder bodies be not of an equal temperature, the heat of the firſt-mentioned body will eſcape quicker from that ſide of it, which is oppoſed to the coldeſt of the ſurrounding bodies; and if a ſcreen be interpoſed between thoſe two bodies, then the loſs of heat will be leſs expeditious. Now upon the leaſt reflection, it will appear, that the experiment with the thermometer and the ice is a ſimilar caſe, excepting that the heat, or caloric, inſtead of proceeding directly from the former to the latter, is reflected and concentrated by the reflectors.

The artificial production of cold is by no means ſo eaſy as the production of heat; but it muſt at the ſame time be confeſſed, that the former is not ſo eſſentially neceſſary as the latter.

The methods of cooling known, and moſtly practiced wherever the heat of the climate or the habits of life render it deſirable, are, 1ſt, by ventilation; 2dly, by employing the natural temperature of caves, wells, and the like, when that temperature is below the temperature of the external air; 3dly, by evaporation; 4thly, by the uſe of ice, where ice can be had; and, 5thly, by the ſolution of certain ſalts.

There is however another operation, which produces cold; but the difficulty of the performance renders it impracticable in common affairs. This is by the expanſion of compreſſed air.

I. The effects of ventilation (ſuch as is produced either by means of a judicious diſpoſition of doors, paſſages, &c. or by means of fans, bellows, and ventilators) are ſo commonly known, that little need be ſaid concerning them. By ventilation the heated air which ſurrounds animal bodies is removed, and the ſenſible or inſenſible perſpiration is more effectually diſſipated; hence a few degrees of cold are produced upon the animal bodies when their temperature is above the actual temperature of the air; but mere ventilation produces no effect upon a thermometer, or upon a body which is of the ſame temperature with the ambient air.

II. In moſt of the warm countries it is commonly practiſed to cool fruit, wines, &c. by keeping them a certain time in deep caves, cellars, and wells; or to place them in water juſt raiſed from deep wells.

This method produces a very moderate refrigeration, for it has been already mentioned that the temperature of thoſe wells, caves, &c. does not differ much from the mean temperature of the country. Yet certain it is that fruit and wines thus cooled in ſummer, prove very pleaſant. But a more eſſential benefit is derived from the uſe of caves and deep wells in warm countries; which is, that meat, fiſh, butter, and other things, are preſerved free from corruption conſiderably longer in thoſe places than in the open air above ground.

III. The cooling by means of evaporation is proportionate to the quickneſs of the evaporation: therefore thoſe fluids, which evaporate quickeſt, produce the greateſt refrigeration; and whatever promotes the evaporation, ſuch as ventilation, a dry ſtate of the air, &c. does likewiſe increaſe the refrigeration.

In warm climates the apartments of the opulent are often rendered pleaſantly cool by ſprinkling water on the floors, on the tops of the houſes, and eſpecially upon the curtains of windows and doors; taking care to renew the ſprinkling as ſoon as the former is evaporated.

In encampments, in travelling through hot countries, or where no other refrigeration can be uſed, it is generally practiſed to wrap up bottles and jars full of liquor, in two or three folds of wet linen, and to expoſe them to a free current of air, taking care to wet the linen coverings in proportion as the water evaporates from them. By this means the water or other liquor within the bottles, is cooled a few degrees.

But the cold which the evaporation of water produces, is inferior to that which can be produced by the evaporation of ſpirit of wine, and vaſtly leſs than that which the evaporation of ether produces; ether being ſo very evaporable, that were it not for the uſual preſſure of the atmoſphere, it would only exiſt in an aëriform ſtate; and ſuch is the caſe under the exhauſted receiver of an air-pump.

In order to try the degree of refrigeration produced by the evaporation of different fluids, I held up a naked thermometer, (viz. a thermometer the bulb of which was not in contact with the metal of the ſcale) and poured upon its bulb a ſtream of ſome particular fluid, which iſſued out of the capillary aperture of a tube; taking care to throw juſt fluid enough to ſupply the waſte by evaporation. By this means, when the temperature of the air was 64°, I found that the evaporation of water cooled the thermometer 8°, viz. brought it down to 56°; the evaporation of ſpirit of wine cooled it 16°, viz. brought it down to 48°; and the evaporation of ether cooled it 54°, viz. brought it down to 10°: but by the uſe of the beſt purified ſulphuric ether, when the temperature of the air was

about

about 56°, I brought the thermometer down to 3°[*].

Some years ago I contrived a very ſmall apparatus for freezing a ſmall quantity of water, viz. about 10 grains, in every climate. The whole apparatus is contained in a box 4 ½ inches long, 2 inches broad, and 1 ½ deep. This apparatus, and the manner of uſing it, is repreſented in Plate XVIII. fig. 20. EFG is a common phial with a glaſs ſtopple, and full uf ether; ED is a glaſs tube with a capillary aperture at D, and having ſome thread wound round the other extremity for the purpoſe of fitting the neck of the bottle when the experiment is to be performed. AB is a glaſs tube about 4 inches long, and about one-fifth of an inch in diameter, hermetically cloſed at B. Into this tube a ſlender wire H is introduced, the lower extremity of which is ſhaped into a ſpiral, and ſerves to draw out the ice when formed. When a little water, CB, is put into the tube, I hold the tube by its upper part with the fingers of the left hand, and keep it continually but gently turning round its axis, firſt one way and then the other; whilſt with the right hand I hold the phial in ſuch a manner as to direct

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[*] The cooling produced by the evaporation of other fluids need not be mentioned; their effect being generally intermediate between the effect of water and that of ſpirit of wine. See my Paper in the Philoſophical Tranſactions, vol. 71, p. 511.

the ſtream of ether, which comes out of the capillary aperture D, towards the outſide of the tube, a little above the ſurface of the water within. The ſtream of ether ſhould be ſuch as that a drop of ether may now and then, (for inſtance every 10 ſeconds) fall from the under part of the thermometer. By continuing this operation during 2 or 3 minutes, the water CB will be frozen, and may be drawn out of the tube in one hard lump of ice. When this is done, the phial is turned with its aperture upwards, the ſhort tube ED is removed, the ſtopple is placed in its ſtead, and the remaining ether is preſerved for other trials.

If ether be placed in an open veſſel, together with a thermometer under the receiver of an air-pump; on exhauſting the receiver, a very great degree of cold will be produced. A mixture of ſulphuric and muriatic ether will produce (by the exhauſtion) cold enough to freeze quickſilver.

IV. The application of ice to the outſide of veſſels full of liquors or other ſubſtances, is the moſt obvious way of producing refrigeration. But ice cannot be procured in all countries; and when it can be procured, which is in the winter ſeaſon, it muſt be preſerved for the ſummer, at which time it is moſtly wanted.

Ice, or ſnow, well rammed cloſe together, is preſerved in reſervoirs, or *ice-houſes*, which are generally made juſt below the ground in ſome ſheltered place, wherein the ice melts very gradually. In this

this climate an ice houſe of 20 feet in diameter, and about 20 deep, properly filled with ice, will be found to contain ſome of it even after two years.

A very remarkable manufactory of ice is practiſed in the Eaſt Indies at Allahabad, Mootegil, and Calcutta, which places lie between 23° $\frac{1}{2}$ and 25° $\frac{1}{2}$ of North latitude. The following is a ſhort account of the proceſs, which is deſcribed at large by Sir Robert Barker in the 65th volume of the Philoſophical Tranſactions.

Boiled ſoft water is poured into ſhallow and porous pans, which are ſituated towards the evening in ſhallow pits, the bottoms of which are ſtrewed with ſugar canes or dried ſtems of corn. In the courſe of the night, and eſpecially towards the morning, a cruſt of ice is formed in the pans, and is collected by the ice-makers. This cruſt of ice differs in thickneſs according to the temperature of the air and other circumſtances favourable to evaporation; for a great part of the effect is undoubtedly due to the evaporation through the pores of the pans, ſince in thoſe countries the thermometer was never obſerved to ſink ſo low as 32°.

Ice by itſelf cannot communicate a greater degree of cold than itſelf poſſeſſes; but by the admixture of common and other ſalts, or of acids, it may be cauſed to produce a much greater degree of refrigeration.

The proportion of common ſalt and pounded ice, or ſnow, which produces the greateſt cold, is variouſly

variouſly ſtated; but 3 parts, by weight, of common ſalt to 8 of ice, or 1 of ſalt to 2 of ice, is the neareſt, and is capable of lowering the thermometer to —4°.

The degrees to which the thermometer is brought down by the mixture of ice and other ſubſtances, are as follows, the materials before the mixture being at 32°.

Snow or pounded ice,	and nitrous acid*	—27°.
	and muriatic acid*	—21°.
	6 parts, and 4 parts of diluted ſulphuric acid, viz. equal parts of water and acid	— 3°.
	24, common ſalt 10, ſal ammoniac 5, and nitre 5	—18°.
	12, nitrous ammoniac 5, and common ſalt 5	—25°.
	2, and muriate of lime 3	—50°.

V. The refrigeration which may be produced merely by the ſolution of ſalts, is very great; indeed as great as may be produced by any known means. But for the knowledge of its greateſt effects, we are

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* The quantity of thoſe acids cannot be ſtated with accuracy, on account of their differing in ſtrength. In general, about equal quantities of diluted acid and of ice may be uſed. The acid, when very ſtrong, may be diluted with half its weight of rain or diſtilled water.

indebted to Mr. Richard Walker of Oxford; for what was known before was, that the ſolution of nitre in water produced a degree of refrigeration ſufficiently uſeful in hot climates; which ſolution has long been in uſe, as it is at preſent uſed in the Eaſt-Indies; alſo, that the ſolutition of ſal ammoniac produced cold ſufficient to lower the thermometer to about 32°, the ſolutions of ſome other ſalts being known to produce a very few degrees of refrigeration; whereas Mr. Walker diſcovered ſuch ſaline ſolutions, and ſuch modes of employing them, as to freeze even quickſilver in the middle of ſummer *.

For this purpoſe the ſolution of the ſaline ſubſtance is made by putting the proper quantity of ſalt and of water in an open veſſel, in the middle of which another veſſel with the wine, cream, or other materials to be cooled, is ſituated. The cold is produced only whilſt the ſalt is diſſolving; viz. the caloric of the annexed bodies is abſorbed by the ſaline ſubſtance, whoſe capacity is increaſed by its being converted from a ſolid into a fluid ſtate.

The cold produced is greater in proportion as the temperature of the materials was lower previous to

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* See his Papers in the Philoſophical Tranſactions, vol. for the years 1787, 1788, 1789, 1795, and for the year 1801; or his publication, entitled, *An Account of the Remarkable Diſcoveries in the Production of Artificial Cold.* Oxford, 1796.

the making of the mixture. Therefore, when a very great degree of cold is to be produced, viz. ſuch as to freeze quickſilver, then a ſolution of ſalts in water muſt be firſt uſed for cooling the materials neceſſary for a ſecond mixtre, which of courſe will be able to produce a greater degree of cold; and by the like means the materials for a third mixture may be cooled, &c.

The following liſt contains the moſt powerful mixtures of ſalts and water, or acid, for the production of cold. The materials are ſuppoſed to be at the temperature of 50° before the mixture, and annexed to each mixture is the degree of cold produced, or the degree to which the thermometer is brought down. The ſalts muſt be powdered very fine, and dry; but not ſo as to have loſt the water of cryſtallization.

N. B. Some of the ſubſtances in the following liſt are expreſſed by their old names, they being ſo expreſſed by Mr. Walker; but from what has been ſaid in vol. 2, the reader may eaſily recollect, that ſal ammoniac is muriate of ammoniac, Glauber ſalt is ſulphat of ſoda, and vitriolic acid is ſulphuric acid.

	Cold produced.
* Sal ammoniac 5, nitre 5, water 16	10°.
Sal ammoniac 5, nitre 5, Glauber's ſalt 8, water 16 - - -	4°.
* Nitrous ammoniac 1, water 1 - -	4°.
Nitrous ammoniac 1, ſal ſodae 1, water 1	—7°.
† Glauber ſalt 3, diluted nitrous acid 2	—3°.
Glauber ſalt 6, ſal ammoniac 4, nitre 2, diluted nitrous acid 4 - - -	—10°.
Glauber ſalt 6, nitrous ammoniac 5, diluted nitrous acid 4 - - -	—14°.
Phoſphorated ſoda 9, diluted nitrous acid 4 - - - - -	—12°.
Phoſphorated ſoda 9, nitrous ammoniac 6, diluted nitrous acid 4 - -	—21°.
† Glauber ſalt 8, marine acid 5 - -	0°. ‡
† Glauber ſalt 5, diluted vitriolic acid 4	3°. ‡
* Muriate of lime 5, water 4 - - -	21°.

The

The following extracts from Mr. Walker's account of his Experiments on Cold, may be of uſe to the reader.

“I have,” ſays he, “frequently frozen quickſilver by “mixing together at 0°, three drams of ground ice, with “two drams of nitrous acid.

“If

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* Theſe ſalts may be recovered by evaporation to dryneſs, and may be uſed again and again repeatedly.

† Theſe ſalts may be recovered by diſtillation and cryſtallization.

‡ The cold in theſe mixtures may be increaſed by the addition of ſal ammoniac and nitre.

The laſt-mentioned method of producing cold, is by the expanſion of air. But this method, which is eſtabliſhed by a ſufficient variety of facts, has not, however, been applied to any œconomical uſes.

It has been found that whenever air is compreſſed in any veſſel, heat is produced, the degree of which is proportionate to the quickneſs of operation and the quantity of compreſſion. On the contrary, when air is expanded, a degree of cold is produced, which is proportionate to the quickneſs and quantity of expanſion.

A thermometer placed under the receiver of an air-pump, is lowered a few degrees, by expeditiouſly rarefying the air of the receiver.

" If it be required to make it perfectly ſolid and hard, a " mixture of equal parts of the diluted vitriolic acid and " nitrous acid ſhould be uſed with the powdered ice; but " then the materials ſhould not be leſs than — 10° before " mixing.

" If a ſtill greater cold be required than a mixture of that " kind can give, which is about —56°, the diluted vitriolic " acid alone ſhould be uſed with ſnow or powdered ice, and " the temperature at which the materials are to be mixed " not leſs than —20°."

If Glauber's ſalt be added in cryſtals unpounded to double aqua fortis, or diluted nitrous acid, even at a warm temperature, the cold produced will be ſufficient to freeze water or cream.

In

In the ſame veſſel the air may be alternately rarefied and condenſed by the uſe of a proper engine, and the thermometer in it will be lowered in the former caſe, and raiſed in the latter *.

If the compreſſed air in the reſervoir of an air-gun, be diſcharged on the bulb of a thermometer, the mercury in the tube of the thermometer will deſcend a few degrees †.

In the Chemnicenſian mines in Hungary, the air in a large veſſel is compreſſed by a column of water 260 feet high, when the ſtop-cock, which gives exit to that air, is opened, the air ruſhes out with great violence, and its expanſion produces a ſurpriſing degree of cold; for the moiſture is precipitated from it in the form of ſnow, and icicles adhere to the noſel of the ſtop-cock ‡.

Having deſcribed the different means of producing heat and cold, I ſhall conclude this Section upon Heat or Caloric, by briefly mentioning an inſtance of the infinite wiſdom of nature in the appli-

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* Philoſophical Magazine, vol. 8, p. 214.

† See Dr. Darwin's Paper in the Philoſophical Tranſactions, vol. 78.

‡ See the deſcription at large of the machine, and the account of the phenomenon in the 52d vol. of the Philoſophical Tranſactions.

cation

cation of proper means for the preſervation of the animal creation in great heats or colds.

The range of temperature in which a human being can live with comfort, is trifling indeed. Natives of different climates can ſuffer without uneaſineſs different, but not very different, degrees of temperature. In this climate we can live with comfort between the temperatures of 60° and 70°, viz. a range of about 10°. When the temperature of the air is below 60°, moſt people would be glad to approach the fire; above 70°, moſt people complain of the heat.

But nature has made ample proviſion for obviating the pernicious effects of a ſudden increaſe of great heat or cold. It is a diſpoſition for generating cold in the former, and heat in the latter caſe, at leaſt to a certain degree and for a certain time; and this is effected by the natural change of capacity in ſome of the component parts of the animal body; thus, for inſtance, when the body is very warm, its perſpiration is increaſed, and the fluid, which becomes vapour, having its capacity for caloric increaſed, contributes to cool the body; and a ſimilar effect is produced by the change of the capacity of other animal fluids, &c.

In fact, animals of various ſpecies, and even human beings, have frequently been expoſed to exceſſive degrees of heat or cold for a certain time, without receiving any material injury; and without having had the natural temperature raiſed or lowered by more than a very few degrees. Thus men have been expoſed to a temperature where quickſilver would freeze, and on the other hand, to a temperature above that of boiling water *.

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* See the experiments in an heated room, in the Philoſophical Tranſactions, vol. for the year 1775.

SECTION II.

ELEMENTS OF OPTICS, OR OF LIGHT, COLOURS, AND VISION.

THE ſubject of the preſent ſection is ſo very extenſive, that a full inveſtigation of all its branches, both in theory and in practice, would fill up ſeveral ſuch volumes as the preſent. A uſeful and competent explanation of its principles is what can be expected in the preſent work; and this we ſhall endeavour to render as comprehenſive as the nature of the ſubject ſeems to admit of. With this object in view we ſhall take little notice of what is merely hypothetical or controverted; we ſhall however refer the inquiſitive reader to thoſe works which treat more at large of thoſe particular branches. With reſpect to the uſeful part of the ſubject, we ſhall endeavour to explain the principles chiefly; for when theſe are well underſtood, a very moderate degree of ingenuity on the part of the ſtudent, will enable him to apply them either for the explanation of new facts, or for the improvement of particular branches.

CHAPTER I.

OF THE NATURE OF LIGHT IN GENERAL.

THE difference, in the day time, of what we perceive when our eyes are open and when our eyes are ſhut, is produced by what is called *light*. The privation of light, as when our eyes are ſhut, is called *darkneſs*. It is this light that informs us of the preſence of objects which are not near enough to touch our bodies, or which do not affect any of our other ſenſes. Hence the blind muſt judge of the preſence of particular objects, by the ſound, or by the ſmell, or by the touch, &c. but not by the means of light. In ſhort, light does not ſenſibly affect any other part of our frames, beſides the eyes.

We have no certain knowledge with reſpect to the nature of light. A variety of conjectures have been made, and a variety of hypotheſes have been offered concerning it; but of thoſe hypotheſes two only deſerve to be mentioned.

It was ſuppoſed by Deſcartes, Huyghens, and others, that a very ſubtile fluid is diſperſed throughout, or fills up, the univerſe; that the luminous bodies, ſuch as the ſun, a candle, a fire, &c. put

that

that fluid, not in a progreſſive, but in a certain vibratory motion; and that this motion, being communicated to the nerves of our eyes, renders the luminous bodies perceptible to us; ſomewhat like the effect of a ſounding body upon the air, which puts the air in a certain vibratory motion, and this motion being communicated to our organs of hearing, excites in us the ſenſation of ſound.

Newton and his followers ſuppoſed that light is a real emanation from luminous bodies; viz. that a ſubtile fluid, conſiſting of certain peculiar particles of matter, proceeds from the luminous bodies, and by entering our eyes, excites in us the ſenſation of light, or the perception of the luminous objects.

A variety of facts and conſiderations ſeem to place Newton's hypotheſis on a baſe of greateſt probability.

Admitting then Newton's hypotheſis, ſeveral conſequences, which are naturally deduced from it, demand a particular explanation; viz. this emanation, this light, muſt conſiſt of particles; thoſe particles muſt have a very minute, but determined, ſize; they muſt be at a certain diſtance from each other, muſt move with a certain velocity, and muſt have a certain momentum.

Several remarkable diſcoveries made in aſtronomy and in other branches of natural philoſophy, enable us to determine the above-mentioned ſize, diſtance, velocity, &c. of the particles of light, not with abſolute preciſion, but within certain limits of probability. Previous to the ſtatement of thoſe quantities, it will be neceſſary briefly to mention the principal facts upon which the determinations of thoſe quantities are eſtabliſhed.

If a ſmall hole be made in a ſcreen, and the ſcreen be placed before our eyes, at about the diſtance of 5 or 6 feet; and if a luminous body, for inſtance, a red-hot coal, be repeatedly paſſed by the hole on the other ſide of the ſcreen, we muſt naturally perceive the hole luminous at intervals. But if the interval, or the time during which the coal is not before the hole, be leſs than the tenth part of a ſecond, then the hole will appear to us conſtantly luminous, exactly as if the red-hot coal were held ſteadily before it. This ſhews that the impreſſion of light upon our eyes continues a certain time, viz. the appearance of an object remains upon our eyes a certain time after the removal of the object, or after the ceſſation of the impreſſion.

It is for this reaſon, that if a ſtick with a lighted extremity be turned round in a circle before our eyes, and if the revolution be quick enough, we perceive not a ſucceſſion of light along the circumference of the circle, but we imagine to ſee an uninterrupted circle of light.

Now it muſt be remarked, that the duration of the impreſſion of light upon our eyes, is longer or ſhorter, according as the object is more or leſs luminous, viz. according as the impreſſion is ſtronger or weaker; hence, if the above-mentioned experiment

ment be performed with a ſtick whoſe extremity is barely red-hot, the revolution muſt be made quicker; but if that extremity be very vivid, then the revolution needs not be ſo quick, in order to repreſent an uninterrupted circle.

The impreſſion is ſometimes ſo ſtrong, that the eye does not eaſily recover its tranquillity, even after ſeveral minutes; and the very ſhape of the luminous object remains a certain time in it. Thus, after having looked for a ſhort time at the ſun, or at the bright fire of a large furnace, the eye remains dazzled, ſo as to render the appearance of other objects defective or confuſed for a very conſiderable time.

It has been obſerved by aſtronomers, that the eclipſes of the ſatellites of the planet of Jupiter, appear to take place ſooner than the time determined by the tables of their motion, when that planet is nearer to us; and that thoſe eclipſes appear to take place later when that planet is farther from us. Hence it is conjectured, that light moves progreſſively and equably, viz. that it employs a certain time in percurring a certain ſpace; and this conjecture is corroborated by other aſtronomical obſervations, which, as well as the abovementioned appearance of the ſatellites of Jupiter, will be explained in a ſubſequent part of theſe elements. But we muſt not omit to mention in this place, that from the difference between the neareſt and fartheſt diſtances of Jupiter from us, and from the difference of time between the apparent and the tabular times of the eclipſes of its ſatellites at thoſe two ſtations of the planet; it has been computed that light moves at the aſtoniſhing rate of, at leaſt, 164000 miles per ſecond, or, we may ſay, 170000 per ſecond; ſo that in moving from the ſun to us, light employs about 8 ¼ minutes; whereas, if a cannon ball could continue to move with the ſame velocity with which it firſt comes out of the cannon, (viz. at the rate of about one-eighth part of a mile per ſecond) it would employ 32 years in going from the earth to the ſun.

If a ſmall hole be made in a ſcreen, and ſeveral perſons be ſituated on one ſide of the ſcreen, every one of them looking through the hole at a different object placed on the other ſide of the ſcreen; it is evident that the various ſtreams of light from thoſe objects to the eyes of the obſervers, muſt paſs through the ſame ſmall hole in different directions, and without diſturbing each other, at leaſt in any obſervable degree. This ſhews that the particles of light muſt be ſo very ſmall and ſo diſtant from each other, as not ſenſibly to obſtruct each others paſſage through a very narrow ſpace.

From ſome imperfect experiments made by throwing the focus of a concave mirror on the extremity of a very delicate beam nicely ſuſpended, by which means a ſlight motion was given to the beam, it was deduced that the light thus collected, had a ſenſible momentum. Now, from the weight of the beam, and from the motion which was communicated

cated to it by the impulſe of light (if that was the real cauſe of its motion); alſo from the above-mentioned velocity of light, it was calculated*, that the matter contained in the light which was thrown upon the end of the above-mentioned beam during one ſecond of time, and which was collected from a reflecting ſurface of about 4 ſquare feet, amounted to no more than one twelve hundred millionth part of a grain †.

Now, from the above-mentioned facts, as alſo from the common, obvious, and daily experience, we may draw the following concluſions:

1. Since every phyſical point of a luminous object may be ſeen from every point of an immenſe ſpherical ſpace which ſurrounds it, when no opaque body interferes, it follows, that the ſtreams of light which proceed from all the points of viſible objects, and move in all manner of directions, is paſt all conception. If this be alledged as an objection to Newton's theory, the leaſt reflection will ſhew, that it offers an objection equally great, if not greater, to the other hypotheſis. But the following conſiderations will ſmooth the difficulty with reſpect to Newton's hypotheſis.

2. It has been ſhewn above, that the impreſſion of

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* See the manner of making ſuch computations in the firſt volume of theſe Elements. Chap. IV.

† Prieſtley's Hiſtory of Diſcoveries on Light, Viſion, &c. Period VI. Sect. I. Chap. III.

of light remains a certain time upon our eyes, and (in the caſe of the red-hot charcoal) it has been ſhewn to remain about one-tenth part of a ſecond; but ſuppoſe it to remain only during the 100dth part of a ſecond; then it is evident, that if 150 particles of light be emitted from a ſingle point of a luminous body, as from a point of the ſurface of the ſun; thoſe particles will be more than ſufficient to give our eyes an uninterrupted viſion of that point; yet ſtill thoſe particles, on account of their immenſe velocity, may be more than 1000 miles diſtant from one another, and of courſe leave room enough for millions of other particles to paſs in all directions *.

3. The waſte of the matter of a luminous body, ariſing from the emiſſion of light, conſidering the minuteneſs of its particles, is very trifling, even with reſpect to the ſun, which has been the great fountain of light during ſo many centuries. Dr. Prieſtley, after having related the experiment which we have deſcribed in page 137, viz. where the focus of a reflector was thrown upon the arm of a ſlight beam, thus reaſons upon it. "Now," ſays he, "the "light in the above experiment was collected from "a ſurface of about 4 ſquare feet, which reflecting "only about half what falls upon it, the quantity "of matter contained in the rays of the ſun, inci-

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* See Mr. Canton's Computation in the Philoſophical Tranſactions, vol. 58, p. 344.

"dent

" dent upon a ſquare foot and half of ſurface, in one " ſecond of time, ought to be no more than the " twelve hundred millionth part of a grain. But " the denſity of light at the ſurface of the ſun is " greater than at the earth, in the proportion of " 45000 to 1 *; there ought, therefore, to iſſue " from one ſquare foot of the ſun's ſurface in one " ſecond of time, in order to ſupply the waſte by " light, one-forty thouſandth part of a grain of " matter, that is, a little more than two grains in a " day, or about 4752000 grains, which is about " 670 pounds avoirdupois, in 6000 years †."

4. On account of the motion of light, it is evident that if a luminous body were ſuddenly placed in the heavens, at, for inſtance, the ſame diſtance that the ſun is from us, we could not poſſibly ſee it before the lapſe of 8 ¼ minutes. Alſo, when we behold a celeſtial object, we do not ſee it exactly in the place where it actually ſtands; but we ſee it in the place where it ſtood ſome time before.

5. Light moves in ſtraight lines as long as it goes through the ſame uniform ſubſtance, or through a vacuum.

6. If we direct our eyes towards certain poliſhed ſurfaces, we frequently ſee in them the appearances of objects which are ſituated in places quite different

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* See the 1ſt vol. of theſe Elements, p. 62.

† Hiſt. of Diſc. on Viſion, Light, and Colours, p. 390.

from thoſe in which we ſee them. Thus an eye at C, fig. 14. Plate XVIII. directed towards the flat and poliſhed ſurface, of which A B is the ſection, will perceive the exact figure, colour, &c. of a body which actually ſtands at D; but which will appear as if it ſtood at E; it is, therefore, evident that the light which proceeds from D, falls upon the ſurface A B, and thence it comes in another direction, F C, to the eye at C. Now the ſurface A B, which thus ſends the light back, is called the *reflecting ſurface* or *mirrour*, be its figure flat or otherwiſe ſhaped. The light thus ſent back, viz. F C, is called the *reflected light*; whereas the light from the object D to the reflecting ſurface, is called the *incident light*. The angle which the incident light makes with the perpendicular to the reflecting ſurface at the point of incidence, viz. the angle D F G, is called the *angle of incidence*. The angle, which the reflected light makes with the ſame perpendicular, viz. the angle C F G, is called the *angle of reflection*. But ſome authors call the angle D F A the angle of incidence, and the angle C F B the angle of reflection.

7. In paſſing from one body into another, or from a vacuum into any ſubſtance, and *vice verſa*, light is often bent in its direction. That bending is called *refraction of light*. Thus, if a lighted candle G, fig. 1. Plate XIX. be placed on the ſide of a veſſel full of water, A B D C, ſo as to caſt a ſhadow of the ſide of the veſſel upon the bottom, the edge of the ſhadow does not come to E, ſo as

to form a ſtraight line EBG, but will be found ſomewhere elſe, as at F, and FBG will form an angle at the ſurface of the water, which proves beyond a doubt, that the light which proceeds from the candle is refracted, viz. bent, at the ſurface of the water. The angle which the incident light GB makes with the perpendicular to the ſurface at B, viz. the angle GBK is the *angle of incidence*; the angle which the refracted light makes with the ſame perpendicular produced, viz. the angle CBF, is called the *angle of refraction*. But ſome authors call the angle GBI the angle of incidence, and FBA the angle of refraction, viz. the angles which the incident and the refracted light make with the ſurface ABI.

8. Light is likewiſe bent not only by paſſing through, but by paſſing within a ſhort diſtance from bodies. This ſort of bending is called *inflection of light*.

An indefinitely ſmall quantity of light, which is neither diverging nor converging, is called a *ray of light*. The quantity of light which comes from a luminous point in a diverging conical manner, is called a *pencil of light*, or a *pencil of rays of light*.

Thoſe bodies, ſuch as water, glaſs, &c. through which light will paſs, or through which our eyes can perceive objects ſituated on the other ſide, are called *tranſparent bodies*. All tranſparent bodies, as alſo a vacuum, are called *mediums* in optics. Thoſe bodies

bodies which obſtruct the paſſage of light, or through which nothing can be ſeen, are called *opaque bodies*.

The ſcience of *optics* comprehends whatever belongs to light and viſion, but ſome authors confine it merely to the explanation of direct viſion, viz. when the light comes directly from the object to the eye. That branch of optics, which treats of reflected light is called *Catoptrics*; and that which treats of refracted light is called *Dioptrics*.

It is upon the reflection and refraction of light, that the whole ſcience of optics principally depends; for if the rays of light were neither reflexible nor refrangible, we ſhould be deprived of teleſcopes, microſcopes, ſpectacles, and all other optical inſtruments; as alſo of the greateſt part of the moſt uſeful and admirable phenomena of viſion.

CHAPTER II.

CATOPTRICS, OR OF REFLECTED LIGHT.

OF the rays of light which proceed from a luminous body [*], thoſe which fall upon the ſurfaces of almoſt all bodies, whether tranſparent or opaque, ſolid or fluid, are more or leſs, but never entirely, reflected [†].

When

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[*] A luminous body, in this place, means any viſible object, whether it be viſible by the emiſſion of original light, like the ſun, a candle, &c. or by reflected light, like the moon, a tree in the day time, &c.

[†] Of the light which falls upon the ſurface of mercury, not above three quarters are reflected; and probably there is no ſubſtance which reflects light ſo well as mercury.

The quantity of light which is reflected from a given flat ſurface, varies with the angle of incidence; and a greater quantity of light is reflected when the angle of incidence is great, than when it is ſmall. Thus of the light of the ſun, which falls upon the ſurface of ſmooth water, a greater quantity is reflected ſoon after ſun-riſe, or before ſun-ſetting, than at noon. But the increaſe of reflected light, with the increaſe of the angle of incidence, is not equally regular with

When the reflecting ſurface is flat, or of a regular figure, then the direction of the reflected rays may be traced by the method which will be explained in the ſequel; but when the reflecting ſurface is irregular, then the light is ſcattered in various and uncertain directions.

The rays, which proceeding from any ſingle luminous point of an object, fall upon a given reflecting ſurface (or upon any ſurface) are innumerable; ſince the reflected appearance of that point may be ſeen by innumerable ſpectators placed in different ſituations, and directing their eyes towards the reflecting ſurface. Thus the luminous object C, fig. 2. Plate XIX. ſends out rays of light ſpherically, or in all directions. Of thoſe rays the portion C A B falls upon a plane reflecting ſurface, of which A B repreſents the ſection; and are thence reflected to the places D, K, L, M, &c.

It is evident that thoſe rays fall upon the ſurface A B, with different angles of incidence; but if you examine any one of thoſe rays and its reflection, you will find that the angle of incidence is conſtantly

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with all ſorts of reflecting ſubſtances. *Bouguer's Traité d'Optique.*

This ſeems conſonant with the Newtonian theory of light, viz. that light is an emanation, and falls upon bodies with a momentum; ſince an oblique impulſe is more eaſily reflected than a direct one, &c. See the firſt volume of this work.

equal to the angle of reflection; and this is a fundamental law in catoptrics; viz. the angle COH is equal to the angle HOD; CIG is equal to GIL, CEN is equal to NEM, and ſo on; OH, IG, EN, being perpendiculars to the ſurface.

Another invariable law is, that the angle of incidence and that of reflection of the ſame ray, lay in one and the ſame plain, which is perpendicular to the reflecting ſurface. The ray which falls perpendicularly upon a reflecting ſurface, (like CA) is reflected back along the ſame line, for in that caſe the angle with the perpendicular vaniſhes.

It is evident that the rays of light which come from a luminous point, muſt fall divergingly upon any given ſurface; yet when the object is vaſtly diſtant, the divergency of the rays becomes inſenſible; and, in that caſe, they are called *parallel rays.* Thus the rays of the ſun, of the moon, of the ſtars, &c. are reckoned parallel rays. When the luminous point is pretty near, then the rays are ſenſibly diverging. The rays which come from different points of the object to one point of a ſurface, are evidently *converging rays.*

In the following pages we ſhall take notice not of all, but of a few only of, the rays which proceed from certain luminous points of objects; it being evident that the intermediate or adjoining rays, are moſtly regulated by ſimilar laws.

When an eye, as E, fig. 3. Plate XIX. views an object as CD, or AB, directly, ſome of the rays, which proceed from every perceivable point of the object,

object, enter the eye, and the whole quantity of light which thus enters the eye, is circumſcribed by the rays which proceed from the extreme points of the object, viz. C E and DE, or A E and B E. The angle which thoſe extreme rays form at tht eye, viz. the angle C E D, or A E B, is called the *viſual angle*, and it is from the ſize of that angle, that we principally judge of the diſtance of a known object. Thus, ſuppoſing that the objects CD and AB are equal, or that they repreſent the very ſame object ſucceſſively ſituated at different diſtances; it is evident that the farther the object is from the eye, the ſmaller will the viſual angle be.

It muſt likewiſe be obſerved that, the diſtance between the eye and the object remaining the ſame, if by any means the rays of light are bent ſo as to enlarge the viſual angle, then the object will appear larger (or it is ſaid to be magnified); and on the contrary, if the viſual angle be diminiſhed, then the object will appear ſmaller, in which caſe it is ſaid to be diminiſhed.

Now theſe particulars, which have been mentioned with reſpect to the above direct view, are likewiſe true with reſpect to the view reflected by any regular reflecting ſurface.

Let O M, fig. 4. Plate XIX. be a flat reflecting ſurface, F an eye directed towards it, and AB an object placed before it. Draw the extreme rays A D, B G, which, forming their angles of incidence equal to their reſpective angles of reflection, may come to the eye at F *; and the object will appear as if it ſtood at I K, viz. as far behind the reflecting ſurface as it actually ſtands before it; or it will appear as it would by direct view to an eye at C, viz. an eye ſituated as far as to make the diſtance C D equal to D F; which is owing to the lines DC, GC forming an angle at C equal to the angle formed by the lines D F, G F at F. That thoſe angles are equal is eaſily proved by drawing the perpendiculars I E and L N to the reflecting ſurface; for the angle of incidence A D I is equal to the angle of reflection I D F, and equal to the angle E D C †; therefore the angle I D F is equal to E D C, and the angle F D G equal to C D G, ſince the whole angle I D G is equal to the whole angle E D G; each being a right angle. By the like reaſoning it will appear that the angle F G D is equal to the angle C G D; whence it follows, that the triangles D G C and D G F, having two angles of the one equal to two angles of the other, and a correſpondent ſide, viz. D G, common, are equal in every reſpect ‡;

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[*] It is uſeleſs to take notice of thoſe rays, which, coming from the ſame points A and B, fall upon the reſt of the reflecting ſurface, becauſe thoſe rays cannot be reflected to the eye. The rays which come from other points of the object between A and B, and fall upon the ſurface D G, are all included between the extreme rays A D, D F, and B G, G F.

[†] Euclid's Elem. B. I. Prop. 15.

[‡] Euclid's Elem. B. I. Prop. 26.

viz.

viz. D C is equal to D F; the angle at C equal to the angle at F, &c.

It is to be obſerved, however, that an object viewed by reflection from a flat ſurface, as by an eye at F, does not appear ſo bright as if it were viewed from C by a direct view, becauſe ſome light is loſt by the reflections even from the beſt reflecting ſurface; which is owing to the pores, irregularities, &c. of thoſe ſurfaces. What has been ſaid of the inclination of the extreme rays A D and B G, is evidently applicable to all other rays incident upon a plane reflecting ſurface, viz. that on account of the perpendiculars I E, L N, &c. being parallel to each other, the incident rays will be reflected with the ſame inclination to each other as they had before their incidence on the ſurface, viz. they will be parallel after reflection, if they were parallel before; and they will be diverging or converging after reflection, according as they were diverging or converging before, and at the ſame angle.

The reflections from concave or convex reflecting ſurfaces, produce very different effects, becauſe the perpendiculars to the different points of a curve ſurface are not parallel to each other. Thus, ſuppoſe that two parallel rays, as A B, C D, fig. 5. Plate XIX. fall upon a ſpherical convex ſurface H I; draw the perpendiculars to the ſurface at the points of incidence B, D, and thoſe perpendiculars

(EB, FD*) muſt diverge from each other, and of courſe the reflected rays, KB, LD muſt likewiſe diverge from each other; for if a line at D, viz. MD, were parallel to EB, then the reflected ray ND would be parallel to the reflected ray KB; and therefore the real reflected ray DL, diverging from DN, muſt alſo diverge from KB.

A ſimilar reaſoning applied to the reflection of incident parallel rays, from a ſpherical concave ſurface, will prove that they muſt be reflected convergingly. Thus the parallel rays AB, CD, fig. 6. Plate XIX. are reflected in a converging manner from the concave ſurface HBDI; in conſequence of which they muſt meet in ſome point where they croſs each other, after which they proceed divergingly, like the reflected rays BF, DF, which meet at F, croſs each other, &c.

This explanation, which we have applied to parallel rays only, may be eaſily extended to all ſorts of incident rays, viz. to thoſe which come divergingly as well as convergingly; the general law being as follows:

All ſorts of rays of light, viz. whether parallel, diverging, or converging, which fall upon a ſpherically

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* The perpendicular to a curve ſurface at any point, is perpendicular to a plain ſurface touching the curve ſurface at that point. The perpendiculars to any points of a ſpherical concave or convex ſurface, do all meet at the centre of ſphericity, viz. of the ſphere of which the given ſurface is a portion.

rically convex ſurface, are reflected in a more diverging manner, viz. the reflected rays proceed leſs inclined to each other than the incident rays.

All ſorts of rays, which fall upon a ſpherically concave reflecting ſurface, are reflected more convergingly, or leſs divergingly, viz. the reflected rays will be more inclined to each other than the incident rays. But when the reflected rays meet and croſs each other, then beyond that point or focus they proceed divergingly.

Now it has been ſaid in page 147, that if the angle, which the rays, that proceed from the extreme points of an object, form at the eye, is by any means diminiſhed, that object will appear ſmaller, and *vice verſa*; therefore it follows, that an object ſeen by reflection from a convex ſurface, muſt appear ſmaller than if it were reflected from a flat ſurface. Alſo, that an object ſeen by reflection from a concave ſurface, muſt appear larger than if it were reflected from a flat ſurface, to an eye ſituated nearer to the reflecting ſurface than the focus of the reflected rays; but it will appear ſmaller and inverted to an eye ſituated farther than that focus; for as the rays croſs each other at the focus, the upper ray, B F, fig. 6. will become the lower F G beyond the focus F, and the lower D F will become the upper F K.

All the properties of reflecting ſpherical ſurfaces depend upon the foregoing laws; and if the reader wiſh to exhibit them upon paper, for the ſake of illuſtration, he may eaſily perform the neceſſary operatious, viz. he muſt firſt of all draw the curve line which exhibits a ſection of the reflecting ſurface; ſecondly, he draws the incident rays, whether converging, parallel, or diverging; thirdly, he deſcribes the perpendiculars at the various points of incidence; and laſtly, he draws the reflected rays, always making the angle of reflection equal to the angle of incidence. I ſhall therefore enumerate the properties of the ſpherically concave and convex reflecting ſurfaces, without any farther explanation of thoſe properties; but previous to this it will be proper briefly to remove a difficulty which frequently occurs to the learners of optics.

In ſpeaking of parallel rays, it is not to be imagined, that all the rays which come from all the points of an object, and fall upon the eye or upon any reflecting ſurface, are parallel to each other; but it muſt be underſtood of thoſe rays only which proceed from one phyſical point. For inſtance, let us examine the rays which come from three points only of the ſun, and which enter the pupil of an eye. See fig. 7. Plate XIX. The rays which proceed from the point A, in truth form a cone, the baſe of which is the pupil of the eye at D; and its height is from us to the ſun; hence, the various rays which form that cone are ſaid to be parallel, becauſe their inclination to each other is inſenſible; and the ſame thing muſt be underſtood of the rays which

which proceed from the point B, or from the point C; but if we take a ray from the point A, and another from the point C, then thoſe rays form a ſenſible angle at the eye; and it is from this angle ADC that we judge of the apparent ſize of the ſun. The meaſure of that angle is about 32 minutes.

This figure likewiſe ſhews, that the larger the pupil is, the brighter will the object appear; becauſe the larger the pupil is, the greater number of rays it will receive from any ſingle point of the object.

Since in nature an object which is near appears larger and brighter than a ſimilar object ſituated farther from the obſerver; therefore, whenever the appearance of a given object is rendered larger and brighter, we always imagine that the object is nearer to us than it really is.

Of a Spherical Convex reflecting Surface.

The objects reflected from ſuch a ſurface appear always ſmaller than natural, always erect, and always as if they were behind the reflecting ſurface.

The objects never appear exactly of the true ſhape. If the object be a right line, or a plain ſurface, the image or appearance of it will be a curve line, or curve ſurface, becauſe the different points of the object are not equally diſtant from the reflector.

Incident parallel rays, viz. ſuch as come from very

very diſtant objects, are reflected divergingly, and their divergency is ſuch, that if they be produced behind the reflecting ſurface, they will meet at the diſtance of half the radius of convexity; that point is called the *virtual focus* of thoſe rays, and the *principal focus* of the reflector.

Diverging incident rays, viz. ſuch as come from near and ſmall objects, have their virtual focus nearer to the reflecting ſurface than half the radius.

When the incident rays are converging, if the diſtance of the luminous point from the reflecting ſurface be leſs than half the radius of convexity, the reflected rays will have a real focus before the ſurface: otherwiſe they will have a virtual focus behind it.

The reflecting ſurface muſt be underſtood to be a ſmall portion of a large ſphere; for, ſtrictly ſpeaking, the rays reflected from a convex ſurface, cannot have a common virtual focus, and the multiplicity of their foci increaſes with the ſize of the ſpherical portion. This property will be rendered more apparent by what will be ſaid in the following paragraphs concerning the concave reflector.

Of a Spherical Concave Reflecting Surface.

If a luminous object be ſituated at the centre of concavity, (for which purpoſe that object ought to be be a ſingle point) then all the rays which fall upon the concave reflector will be reflected ſo as to meet at that ſame point, or centre, or focus.

Rays which come from any other point, cannot be all reflected to one and the ſame focus. Thus in fig. 8. Plate XIX. AB repreſents the concave reflector, Q is the object or radiant point, and *ffff ooo* repreſent the various foci of the reflected rays, which form the two curve lines *fff ooo.* Thoſe curve lines are called *cauſticks*, or *cauſtics by reflection* *.

The rays which are reflected from the middlemoſt part of the reflector, viz. from that part which is more directly oppoſite to the radiant point, (as the part CD) meet or have their foci pretty near to each other, and the narrow ſpace, within which they meet, is conſidered as the focus of thoſe incident rays. On this account the concave reflectors which are commonly made for optical or other philoſophical purpoſes, generally are ſmall portions of large ſpherical ſurfaces; for whether the reflector is to reflect light or heat to a particular place, as at F, the portions CA and DB will be quite uſeleſs.

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* "Such cauſticks may be ſeen upon the ſurface of milk, or upon any opaque whitiſh mixture of liquors contained in a white china-cup, or upon the bottom of a ſnuff-box, whoſe rim is well poliſhed, when the light of a candle, or of the ſun, or of a remote window ſhines upon it." Dr. Smith's Opticks, B. I. Chap. II.

Therefore in the following paragraphs, by a concave reflector, muſt be underſtood a ſmall portion of a large ſpherical ſurface.

The radiant point, or luminous point, from which the incident rays proceed, is alſo called a focus, like the point in which reflected rays meet; but the former is denominated the *focus of incident rays*, whilſt the latter is called the *focus of reflected rays.*

A line which is ſuppoſed to paſs through the centre of the reflector, and through the centre of the ſphere, of which that reflector is a part, is called the *axis* of the reflector.

When the incident rays are parallel (viz. when the focus of incident rays is very remote) then the focus of the reflected rays is before the reflector at the diſtance of half the radius of concavity, from the reflecting ſurface, and in the middle of that radius to which the incident rays are parallel. This diſtance is called the *focal diſtance.* Such a focus of reflected rays, viz. when its diſtance is equal to half the radius of concavity, is called the *principal focus* of that reflector.

The nearer the focus of incident rays comes to the ſurface of the reflector, the farther will the focus of reflected rays recede from that ſurface; in ſhort, thoſe foci move in contrary directions (1). When the

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(1.) Of the following three quantities, viz. the diſtance of the focus of incident rays, the diſtance of the focus of reflected the diſtance of the focus of incident rays is equal to half the radius of concavity, then the rays will be

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flected rays, and the radius of concavity or convexity, when two are given the third may be found from the following analogy, which applies to convex as well as to concave ſpherical reflectors.

" The diſtance of the focus of incident rays from the principal focus, half the radius of the reflector, and the diſtance between the principal focus and the focus of reflected rays, will be in continual proportion.

" Suppoſe the reflector to be concave, and the rays to diverge from a focus, the diſtance of which from the ſurface $= d$.

" Let the radius of the reflector $= r$; we have, by the preceding rule, $d - \frac{r}{2} : \frac{r}{2} :: \frac{r}{2} : \frac{r^2}{4d-2r}$ = the diſtance between the focus of reflected rays and the principal focus.

" The focus of reflected rays is in this caſe between the principal focus and the centre of the reflector; wherefore, adding $\frac{r}{2}$ to the quantity laſt found, we have $\frac{r^2}{4d-2r} + \frac{r}{2} = \frac{2r^2+4dr-2r^2}{8d-4r} = \frac{dr}{2d-r}$ for the diſtance of the focus of reflected rays from the ſurface.

" This ſolution extends to all caſes of foci formed by reflection from a ſpherical ſurface, by changing the ſign of r, when the reflector is convex, and of d, when the rays converge to a point, the diſtance of which from the ſurface is d; thus, if rays converge upon a concave reflector, the radius of which is 30 inches, and focus of converging rays ſhould be reflected parallel to each other; and when the above-mentioned diſtance is leſs than half the radius of concavity, then the reflected rays will not meet in a focus before the reflector; but they will proceed divergingly, viz. their virtual focus will be behind the reflector.

When an object, as O B, fig. 9. Plate XIX. is ſituated before a concave reflector A R, the rays which depart from any point, as O, and fall upon the reflector, are thereby reflected in a converging manner, ſo as to croſs each other at I; alſo the rays which proceed from any other point, as B, are likewiſe reflected to a focus or point M; and the like thing muſt be underſtood of the intermediate points. Now becauſe thoſe foci are ſituated nearly at the ſame proportional diſtances from each other, as the correſpondent radiant points are in the object OB; therefore it is ſaid, that an image of the object is formed before the reflector; but it muſt not be imagined that a ſpectator ſituated on one ſide, as at C, can ſee the image I M; for though the rays of light meet and croſs at I M, yet they proceed ſtraight on beyond that place, and, of courſe, cannot

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ſhould be 10 inches from the ſurface, the focal length required will be $\frac{-dr}{-2d-r} = \frac{dr}{2d+r}$ in the preſent caſe $= \frac{30 \times 10}{30+20} = 6$. Atwood's Deſcription of Experiments, page 58.

come to the eye at C. The meaning then of an image being formed at IM, is that if a ſolid opaque ſubſtance, as a flat piece of paper, be placed at IM, then the image of the object will be formed on that ſide of the paper, which faces the reflector, and this image will be ſeen by an eye at C, becauſe in that caſe the rays of light are obſtructed in their direct courſe. No image, or a very indiſtinct one, will be formed, if the paper be placed nearer or farther from the reflector than the proper place.

Alſo, if an eye be ſituated before the reflector, as at D, the reflected rays of light will come to it with the ſame inclination as if the object ſtood at IM, but in an inverted poſition; hence it is ſaid, that an inverted image is formed before the reflector.

This likewiſe ſhews what is meant by the expreſſion of an image being formed behind a reflector; namely, that the reflected rays come to the eye with the ſame inclination as if the object itſelf were ſituated behind the reflector.

When an eye views an object directly, the quantity of light which enters the eye from any ſingle point of the object, is a pencil whoſe baſe is equal to the pupil or aperture of the eye, and the ſame is the caſe when the object is viewed by reflection from a plane mirror; but when the mirror is concave, then on account of the inclination which the rays of light ſuffer towards each other, a greater quantity of light from each ſingle point of the object, enters the pupil. This is clearly ſhewn by fig. 10, 11, and 12. Plate XIX. the firſt of which repreſents a direct view, the ſecond a view by the reflection from a flat reflector, and the third a view by reflection from a concave reflector; of the ſame luminous point A.

Hence it is, that an image formed by reflection from a concave reflector, may appear a great deal brighter than the object itſelf.

The image of an object, formed by reflection from a ſpherical ſurface, is never exactly like the original object. Thus the image of a ſtraight line is not a ſtraight line, but a conic ſection; and the kind of the curve is determined by the diſtance of the object.

The intenſity of the light, or of the heat of the ſun, which is produced by the collected rays in the focus of a concave ſpherical reflector, is ſaid to be as the ſquare of the diameter of the reflector directly, and as the principal focal diſtance inverſely. Thus, if two reflectors, A and B, have the ſame radius of concavity, but the diameter of A is 6 inches, and that of B is 18 inches, then the intenſity of light or heat at the focus of A, is to that at the focus of B, as 1 to 9. This proportion muſt not, however, be conſidered as exact.

The property which a concave reflector has of forming an image of an object before its ſurface, has been frequently uſed, either as a real or as an entertaining deception; and contrivances made upon this principle have been frequently ſhewn for money in London and elſewhere. The following is an eaſy conſtruction of this ſort.

A concave mirror, about a foot in diameter, is ſituated behind a partition FD, fig. 13. Plate XIX. and a hole either circular or oblong, of about ſeven inches in length, is made in the partition. An inverted object, for inſtance, a flower, is placed at E, behind the partition, and is illuminated by means of lamps laterally ſituated; alſo a pot or ſtand is placed at D, before the partition. Now the diſtance of the partition, flower, &c. muſt be ſuch as to form the reflected image of the flower juſt over the pot or ſtand D. Then an eye ſituated at C, and looking ſtraight through the hole in the partition, will perceive an image of the flower at I; and when the light is properly managed, viz. that no extraneous light interferes, the illuſion is ſo great, that the ſpectator will frequently extend his hand to graſp what he thinks to be a real flower at I.

Reflecting ſurfaces have been made of various ſhapes, ſuch as cylindrical, conical, &c. but the only uſe that can be made of them is to ſurprize people by ſhewing them a regular figure reflected from an original deformed object; the principle of which may be eaſily comprehended. For inſtance, if you place a regular object before an irregular reflector, the reflected image muſt evidently be deformed; therefore, if the object, ſuch as a picture, &c. be drawn purpoſely deformed, according to certain rules (which may be eaſily derived either from a due conſideration of the form of the reflector, or by trials) then the reflected image will appear regular. Such deformed figures (called anamorphoſes) are ſold by the opticians, together with a cylindrical or conical reflector *.

There is one ſhape, however, for a concave reflector, which is ſuperior to all others, and that is the parabolical; for, as may be eaſily deduced from the Elements of Conic Sections, when rays fall upon a parabolic concave reflector, parallel to its axis, they are all reflected to one and the ſame point, namely, to the focus of the parabola, without ming those cauſtic curves which are produced by ſpherical concave reflectors. But the mechanical difficulty of forming a well poliſhed parabolic reflector is very great, and indeed there is no certain known method of forming it.

The reflection of light from poliſhed ſurfaces of almoſt all bodies, takes place not only when the incident rays, which proceed from the object, paſs through the air, and fall upon the ſurface of the liquid or ſolid; but likewiſe, when the rays travel through the liquid or ſolid itſelf. Thus, let a ſpeck A, fig. 14. Plate XIX. be in a lump of glaſs, B C D E, an eye ſituated at F will ſee the ſpeck in

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* For the methods of drawing thoſe diſtorted figures, ſee Dr. Smith's Optics, B. II. chap. 12. Prieſtley's Hiſtory of Viſion, Light, and Colours, Part II. Sect. V. as alſo moſt other writers on Optics.

the

the direction FG; its incident light AG, being reflected by the ſurface BD; and this reflection becomes very ſtrong or total, when the angle of incidence, AGH, exceeds 40°. The ſame thing takes place in water, and other tranſparent bodies*. Of this more will be ſaid in the next chapter.

A common flat reflector, or *looking glaſs*, conſiſts of a flat poliſhed plate of glaſs, to one ſide of which a plate of tin foil is made to adhere by means of quickſilver. In conſequence of this conſtruction the looking glaſs makes a double reflection of every object, viz. one from the upper ſurface, which is the weakeſt, and another from the under ſurface, which is contiguous to the tin foil. When a perſon ſtands juſt before the glaſs, the two reflections coincide, and he perceives one image; but if he ſtands oblique, as at A, fig. 15. Plate XIX. and views the reflection D, of an object B C, ſituated on the other ſide, he will then perceive two images, viz. one cauſed by the upper, and the other cauſed by the lower ſurface of the glaſs EF. If the object BC be very luminous, ſuch as a lighted candle, then the eye at A will perceive a great ſucceſſion of candles at D, gradually decreaſing in ſplendour; the cauſe of which phenomenon is, that the ſtrong reflection from the under ſurface of the glaſs is again

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* When a ray of light thus paſſing through a medium is reflected by its ſurface, that reflection will be ſtronger the rarer the other medium is which ſurrounds the former.

reflected from the upper ſurface, and this again by the lower, &c.

There is no ſubſtance ſo perfectly tranſparent, but what contains ſome ſmall opaque or reflecting particles, which ſcatter part of the light that would otherwiſe entirely paſs through. This is the reaſon why we ſee the direction of the light, which, entering through a ſmall hole, paſſes through the air of a room, viz. on account of the reflecting particles of ſubſtances that float in the air. Hence we ſee light in a room out of the real direction of the rays which come from the aperture, or window, &c.

When light falls upon a body, and is thence reflected, it is ſuppoſed that the reflection takes place not exactly at the ſurface of the reflecting body, but at a little diſtance from it. One of the proofs of this ſuppoſition is, that bodies which are made ſmooth by art, reflect light regularly; though their ſurfaces, when narrowly examined by means of a magnifier, will be found full of ſcratches and holes.

We ſhall conclude this chapter with the deſcription of a practical method of meaſuring the angles of incidence and reflection, and a method of meaſuring the quantity of light which is loſt by reflection.

There are ſeveral ways of meaſuring the angles of incidence and reflection, but the following is one of the eaſieſt. Let ACB, fig. 16. Plate XIX. be a ſemicircle,

ſemicircle, divided into twice 90 degrees. AB repreſents the ſection of a flat reflector. Cover the ſurface of this reflector with paper, excepting a very ſmall circular ſpot as at D. Place the ſemicircle perpendicularly upon the reflector, and with its centre in the middle of the uncovered ſpot D of the reflector. This done, fix a pin or other ſmall object cloſe to the edge of the ſemicircle, for inſtance, at E, the 50th degree; then move your eye along the ſide A F C of the ſemicircle, and you will perceive the object E reflected by the reflector D, only when the eye is at F, viz. at the 50th degree of the quadrant A F C; whence it appears, that the angle of reflection, C D F, is equal to the angle of incidence E D C.

Bouguer's methods of meaſuring the quantity of light loſt by reflection is deſcribed by Dr. Prieſtley in the following manner. "He placed a mirror, "or reflecting ſurface B, fig. 17. Plate XIX. "on which the experiment was to be made, truly "upright; and having taken two tablets, of pre- "ciſely the ſame colour, or of an equal degree of "whiteneſs, he placed them exactly parallel to one "another, at E and D, and threw light upon them, "by means of a lamp or candle P, placed in a "right line between them. He then placed him- "ſelf ſo that, with his eye at A, he could ſee the "tablet E, and the image D, reflected from the "mirror B, at the ſame time; making them, as "it were, to touch one another. He then moved

“ the candle along the line E D, ſo as to throw
“ more or leſs light upon either of them, till he
“ could perceive no difference in the ſtrength of
“ the light that came to his eye from them. After
“ this he had nothing more to do than to meaſure
“ the diſtances E P and D P; for the ſquares of
“ thoſe diſtances expreſſed the degree in which the
“ reflection of the mirror diminiſhed the quantity
“ of light. It is evident that if the mirror reflected
“ all the rays it received, the candle P muſt have
“ been placed at C, at an equal diſtance from each
“ of the tablets, in order to make them appear
“ equally illuminated: but becauſe much of the
“ light is loſt in reflection, they can only be made
“ to appear equally bright, by placing the candle
“ nearer to the tablet D, which is ſeen by reflection
“ only.

“ To find how much light is loſt by oblique re-
“ flection, he took two equally poliſhed plates, D
“ and E, fig. 18. Plate XIX. and cauſed them
“ to be enlightened by the candle P; and while
“ one of them, D, was ſeen at A, by reflexion
“ from B, placed in a poſition oblique to the eye,
“ the other, E, was ſo placed, as to appear conti-
“ guous to it; and removing the plate E, till the
“ light which it reflected was no ſtronger than that
“ which came from the image of D, ſeen by re-
“ flection at B, he eſtimated the quantity of light
“ that was loſt by this oblique reflection, by the

“ ſquares

"ſquares of the diſtances of the two objects from "the candle.

"I need not add that, in theſe experiments, all "foreign light was excluded, that his eye was "ſhaded, and that every other precaution was ob"ſerved, in order to make his concluſions un"queſtionable*."

Notwithſtanding all thoſe precautions, it muſt be acknowledged that the above-mentioned method of meaſuring the light loſt by reflection is by no means very accurate; nor do I know of any other leſs objectionable. The principal ſources of inaccuracy are, the difficulty of determining, by the judgment of the eye, when two objects appear equally bright, and the want of an accurate experimental proof to confirm the propoſition, that light really decreaſes in proportion of the ſquares of the diſtances from the luminous or radiant point.

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* Prieſtley's Hiſtory of Viſion, Light, and Colours, Part VI. Sect. III.

CHAPTER III.

DIOPTRICS, OR OF REFRACTED LIGHT.

THE object of this Chapter is to ſtate and to explain the various effects which ariſe from the refraction of light through tranſparent mediums.

When a ray of light paſſes from one medium into another, in a direction perpendicular to the contiguous ſurfaces, or to the junction of the two mediums, then that ray proceeds ſtraight on, without any deviation from the ſtraight line.

But when the ray paſſes from one medium into another medium of different denſity, in a direction oblique to their contiguous ſurfaces; then that ray will be bent, ſo as to form a right lined angle at the junction of the two mediums; for the direction of the ray through either of the mediums is rectilinear, as long as the medium is of a uniform denſity; but if the medium be continually varying in denſity, like the air of the atmoſphere from the earth upwards; then the ray of light in paſſing through it will be continually bent, viz. it will form a curve line.

When a ray of light paſſes from a thinner into a denſer medium *, or *vice verſa*, if a perpendicular be drawn to the junction of the two mediums at that point, through which the ray paſſes; then the angle which that ray makes with the above-mentioned perpendicular in the thinner medium, is generally larger than that which it makes with the ſame perpendicular in the denſer medium.

This is otherwiſe uſually expreſſed, by ſaying, that in paſſing from a thinner into a denſer medium, the angle of incidence is generally larger than the angle of refraction, and *vice verſa*.

Now it has been obſerved, that in the paſſage of oblique light through the ſame two mediums, the ſine of the angle of refraction always bears the ſame proportion (either accurately or nearly ſo) to the ſine of the angle of incidence. Alſo in paſſing through any two other mediums, the ſine of the angle of refraction likewiſe bears a certain proportion (either conſtantly the ſame, or nearly ſo) to the ſine of the angle of incidence; but the ratio of thoſe two ſines in the latter two mediums, is different from the ratio of the two ſines in the former two mediums. All this will be illuſtrated by the following explanation of fig. 1. Plate XX.

Let FGXZ be a quantity of water. B repreſents a narrow tube, through which the ſun ſhines,

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* Not all the light incident upon a tranſparent body paſſes through it, but a portion is always reflected from its ſurface.

and, on account of the oblique ſituation of the tube, the ſun's light muſt fall obliquely upon the water at C. Then that light will not paſs through the water along the line CZ, which is in the ſame ſtraight direction with BC; but it will paſs in the direction CD, (which may be clearly perceived, eſpecially if the water be not very clean) making the angle of refraction DCE, with the line ACE, (which is perpendicular to the ſurface of the water, or to the boundary of the two mediums, viz. water and air) leſs than the angle of incidence ACB.

Otherwiſe, ſuppoſe that various objects, for inſtance pebbles, be placed below the water, and that an obſerver at P, looks through the inclined tube B; then the obſerver will perceive, not the pebble Z, but the pebble D; whereas, if the water were drained off, then he would perceive the pebble Z, and not the pebble D.

If a circle FHE be deſcribed about the centre or point of incidence C, in the ſame plain with the lines BC, CD; and from the interſection H of the circle with the incident ray, a perpendicular HK be dropped on the line AE; then HK is the ſine of the angle BCA. Alſo, if from the interſection I of the circle with the refracted ray, a perpendicular IL be dropped on the ſame line AE; then IL will be the ſine of the angle DCE.

Now it has been found that the ſine IL is always nearly three-fourths of the ſine HK, let that ſine be what it may; for inſtance, if the tube B be placed at M, then the ſine of the angle of incidence MCA, will be OR; and the angle of refraction, or of the angle in water, will be YCE, whoſe ſine is YQ; and YQ will, as above, be nearly three-fourths of the ſine OR.

It is evident that when the incident ray comes along the line AC, the angle of incidence, as well as its ſine, vaniſhes or becomes nothing; conſequently the angle of refraction and its ſine muſt vaniſh too, viz. the ray of light muſt proceed ſtraight along the line ACE. Hence it is ſaid, that there is no refraction when the rays of light enter a medium in a direction perpendicular to its ſurface.

Now if, inſtead of water, FGXZ be ſuppoſed to be glaſs, every thing elſe remaining as before, then the difference of reſult will be, that the ratio of the ſine of refraction to that of incidence is (not as it was in the caſe of water, viz. 3 to 4, but) nearly as 2 to 3; viz. the angles of refraction will be reſpectively ſmaller when FGXZ is glaſs, than when it is water. And if, inſtead of water or glaſs, FGXZ were a diamond, then the angle of refraction would be ſmaller ſtill; viz. the ſine of the angle in the diamond would be to the ſine of the angle in air, nearly as 2 to 5.

A conſiderable variety of tranſparent ſubſtances has been thus examined with reſpect to their refractive properties. Their peculiar refractive powers will be ſtated in the ſequel.

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In the above-mentioned example, the light (for inſtance, of the ſun) which paſſing through the tube B, falls upon the water at C, is not only bent, but alſo enlarged in a ſectoral manner, and its enlargement is in the plain C I E B. It is alſo remarkable that the refracted, and enlarged or diſperſed light, is not of one uniform colour, but appears tinged with the colours of the rain-bow.

In fig. 2. Plate XX. which is intended to illuſtrate this wonderful property, I C is ſuppoſed to be a ſmall beam of ſolar light, which paſſes through the air, and enters a refracting medium at C. Through that medium the beam of light will be ſpread in the ſectoral ſhape, $v\,C\,r$, which is called *the angle of diſperſion*, or *diſſipation*, and which is itſelf divided into ſmaller ſectors of different colours; viz. next to the upper line $C\,r$, the light appears red, and thence it gradually degenerates into orange, yellow, green, blue, indigo, and laſtly, violet, which is neareſt to the lower line or boundary $C\,v$.

Now a line $C\,m$, through the middle of the angle $v\,C\,r$, is the mean direction of the refracted light, and $m\,e$ is its ſine, or the ſine of the mean angle of refraction; whereas $v\,f$ and $r\,d$ are the ſines of the extremes, of which $v\,f$ is called the *ſine of the moſt refrangible colour*, and $r\,d$ *the ſine of the leaſt refrangible colour*.

This ſeparation of the white or colourleſs light into various colours, induced Sir Iſaac Newton to conclude, that white light conſiſts, or is a mixture, of different coloured rays, which being differently refrangible, are of courſe ſeparated by the refracting medium. We ſhall preſently treat of the number and other properties of thoſe colours. But it muſt for the preſent be remarked, that through the ſame medium, the angle of diſſipation is always proportionate to the mean angle of refraction, and of courſe when the mean angle of refraction is very ſmall, then the angle of diſſipation muſt be much ſmaller, in which caſe the different colours cannot be diſtinguiſhed: but when the angle of incidence, and conſequently the mean angle of refraction, is conſiderably larger, then the angle of diſſipation will alſo be ſo large, as to exhibit the different colours.

But different refractive mediums have different diſperſive powers; for inſtance, the angle of incidence I C H remaining the ſame, not only the mean angle of refraction m C E, will vary according as the refractive medium A B D G is water, or glaſs, or diamond, &c. but the angle of diſſipation v C r will alſo vary. And in ſome refracting mediums the mean angle of refraction is larger, whilſt the angle of diſſipation is ſmaller; and in other refracting mediums the mean angle of refraction is ſmaller, whilſt the angle of diſſipation is larger. In ſhort, the knowledge of the mean refractive power of a given ſubſtance will not enable us to determine its diſperſive power, and *vice verſa.*

Heat or an increaſe of temperature generally increaſes, but not much, the refractive power of tranſparent bodies, eſpecially of fluids.

The following table contains the mean refraction from air into the following mediums. The firſt column contains the ſubſtances; the ſecond expreſſes the ſine of the angle of incidence, that of refraction being reckoned one or unity; and the third column expreſſes the diſperſive powers in proportional numbers, that of water being reckoned 100. Thus the ſine of incidence is to that of refraction from air into flint-glaſs, as 1,5998 to 1, or as 1,6 to 1. And the diſperſive power of the ſame glaſs is to that of water, as 227 to 100 [*].

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[*] The various articles of this table have been ſelected from the experiments of Newton, Euler, Zeiher, Haukſbee, Martin, Rochon, and others. A vaſt number of other ſubſtances might have been added, ſuch as ſolutions of ſalts, decoctions or infuſions of woods, &c. but theſe have been omitted principally on account of their indefinite and fluctuating quality. See *Diſtilled Vinegar* in the Table.

An idea of the real quantity of the diſperſive power of flint-glaſs may be derived from the following particulars. The ſine of the angle of incidence is to the ſine of the angle of refraction of the leaſt refrangible or red rays from air into flint-glaſs, as 1,5889 to 1; and the ſine of the angle of incidence to that of refraction, of the moſt refrangible or violet rays, as 1,6107 to 1. Of this more hereafter.

	Sine of incidence.	Diſſipation.
White flint-glaſs of the ſpecific gravity 3,29	1,600	180
Glaſs made of minium, viz. red lead, and flint, in the proportion of M 3 : F 1	2,028	709
2 : 1	1,830	524
1 : 1	1,787	482
¾ : 1	1,732	325
½ : 1	1,724	265
¼ : 1	1,664	200
Common plate-glaſs, or coach-glaſs ſp. gr. 2,76	1,573	165
Crown-glaſs, ſp. gr. 2,52	1,532	148
Yellow plate, or Venetian glaſs, ſp. gr. 2,52	1,532	
Brazil pebble, ſp. gr. 2,62	1,532	159
Glaſs tinged red by means of gold, for enamel	1,715	290
Glaſs of *Saint Gobin* in France	1,543	149
A diamond by Newton	2,439	
A diamond by Rochon	2,755	286
* Rock cryſtal	1,561 1,575	121 124
* Iſland cryſtal Newton	1,666	
* Iſland cryſtal Rochon	1,562 1,625	169 233
Amber	1,556	
A yellow pſeudo topaz	1,643	
Glaſs of antimony	1,889	
Alum	1,458	
Borax	1,467	

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* Thoſe tranſparent minerals have a double and often a multiple refraction, viz. an object, ſeen through a piece of any of them, appears double or treble, &c. and each refraction is attended with a different diſperſion. This effect is very evident in the Iſland Cryſtal. There are ſome other tranſparent mineral bodies, which alſo have a double or even a multiple refraction.

		Sine of incidence.	Diſſipation.
Nitre		1,524	
Camphire		1,500	
Gum arabic		1,477	
Fluids.			
Diſtilled water		1,336	100
Rain water		1,336	
Well water between 1,336 and		1,337	
Water ſaturated with common ſalt		1,375	122
Solution of common ſalt, water 27, ſalt 1		1,348	
Solution of ſugar, water 27, ſugar 1		1,346	
Solution of mineral alkali, or ſoda		1,352	
Solution of ſal ammoniac		1,382	134
Solution of vegetable alkali, or pot-aſh		1,390	
Lime water		1,334	
Sulphuric acid		1,426	
Nitric acid		1,412	154
Diſtilled vinegar	Euler	1,344	
	Rochon	1,335	
	Haukſbee	1,372	
Ammonia, or cauſtic volatile alkali		1,349	
Spirit of hartſhorn		1,339	
French brandy		1,360	
Ditto, a ſtronger kind		1,365	
Highly rectified ſpirit of wine, or alcohol		1,371	
Oil of olives		1,465	
Oil of wax		1,452	
Oil of lavender		1,469	
Oil of cinnamon		1,534	
Oil of ſaſſafras		1,544	
Oil of turpentine		1,482	
Spirit of turpentine		1,562	
Oil of amber		1,501	
The cryſtalline humour of an ox's eye		1,463	

The

		Sine of incidence.
The white of an egg	Euler - - -	1,368
	Haukſbee - -	1,351
Vacuum * - - - - - -		0,99974

The following obſervations on the foregoing table are deſerving of notice.

Upon the whole it appears, that the denſer bodies, viz. thoſe of greater ſpecific gravity, refract or bend the light more than thoſe which are leſs denſe; excepting (as Sir Iſaac Newton expreſſes it†) that unctuous and ſulphureous bodies refract more than others of the ſame denſity.

There is no ſubſtance that has an intermediate refractive power between air and rain, or diſtilled

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* "This refraction of the air is determined by that of the atmoſphere obſerved by aſtronomers. For if light paſs through ever ſo many refracting mediums, which are gradually denſer and denſer, the ſum of all the refractions will be equal to the ſingle refraction which it would have ſuffered in paſſing immediately out of the firſt medium into the laſt. And therefore the whole refraction of light, in paſſing through the atmoſphere, muſt be equal to the refraction which it would ſuffer in paſſing, at the ſame obliquity, out of a vacuum immediately into air of equal denſity with that which is in the loweſt part of the atmoſphere." Newton's Optics, B. II. Part III. Prop. 10.

† Optics, B. II. Part III. Prop. 10.

water. The refractive property of the diamond is greater than that of any other known ſubſtance*. Spirituous liquors have a greater refractive power in proportion to their ſtrength. Spirit of turpentine is the moſt refractive of the fluids.

It is now neceſſary to examine the coloured light itſelf, viz. the various colours into which white light (like the ſolar light, candle light, &c.) is divided by refraction. And ſince this diviſion, or the angle of diſperſion in a given medium is proportionate to the angle of incidence; therefore, in order to examine with more accuracy the different colours, &c. it will be neceſſary to let the light of the ſun enter through an hole in a dark room, and to let it fall upon a refracting medium at a great angle of incidence. For this purpoſe, glaſs priſms have been ſound to be the moſt uſeful.

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[*] This property induced Sir Iſaac Newton to conjecture that the diamond is a ſubſtance of an unctuous quality, like oils, reſins, &c. meaning of a combuſtible quality, which was ſome years after actually verified by experiments. Optics, B. II. Part III. Prop. 10. But the ſame conjecture, deduced from other principles, is mentioned by Boetius, previous to Newton. He obſerves, that watery ſubſtances will adhere to other watery ſubſtances, but not to oleaginous bodies, and that oleaginous bodies will adhere to other oleaginous bodies; then adds, "Quod itaque maſtix, "quæ igneæ naturæ eſt, adamanti facile jungi poſſit, ſignum "eſt id propter materiæ ſimilitudinem fieri, ac adamantis "materiam igneam, et ſulphuream eſſe." Gemmarum, et Lapidum hiſtoria, L. II.

Fig. 3. Plate XX. repreſents a triangular glaſs priſm, viz. a lump of glaſs having two triangular and parallel baſes ABC, DFE, and three flat parallelepipedal ſides*. AD, CE, BF, are the angles of the priſm. A line which paſſes through the centres of the baſes is called the *axis*. When a beam of light paſſes through the priſm, by entering at one of its parallelepipedal ſides and going out at another, then the angle formed by thoſe two ſides, is called the *refracting angle of the priſm*.

AB, fig. 4. Plate XX. repreſents part of the ſhutter of the window of a room, wherein no light enters, excepting what comes through the hole C. If this light, ſuppoſing it to be the light of the ſun, be received upon a ſcreen at any diſtance from the hole, as at F, an image of the ſun, or a circular luminous ſpot, will be formed upon the ſcreen, which is larger in diameter than the hole

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[*] Priſms are alſo made hollow, (viz. the ſides are formed of flat plates of glaſs) and are filled with different fluids, in order to determine the refractive power of thoſe fluids. The flat plates are often made to move between two ſolid metal baſes; by which means the refracting angle of the priſm may be altered at pleaſure.

Priſms in general are frequently furniſhed with metal caps and pins at their baſes, as at AB, Fig. 6. Plate XX. by which means they may be commodiouſly turned about their axes.

at C, and that principally on account of the diameter of the ſun; for the rays of light which depart from the various points of the ſun's ſurface, and paſs through the hole, muſt croſs each other at that place, and muſt proceed divergingly, or in a conical form within the room.

Place a glaſs priſm D O E before the hole, ſo that the light may paſs through it in a direction perpendicular to the axis of the priſm; and inſtead of going ſtraight from E to F, the light which comes through the hole will, by paſſing through the priſm, be bent and diſperſed in ſuch a manner as to form a coloured ſpectrum G H upon a ſcreen, which may be ſituated at any diſtance from the priſm, but below the ſtraight direction C F. The angle F E S made by the ſtraight direction, and the mean direction of the refracted light, is called *the angle of deviation.*

The ſpectrum G H (moſt beautiful to the eye) is about five times as long as its breadth, and is terminated by ſemicircular ends. The higheſt part G is of a beautiful red colour, which, by inſenſible ſhades, degenerates into an orange, then a yellow, a green, a blue, an indigo, and a violet, which is the colour next to H, viz. at the loweſt part of the ſpectrum.

From thoſe denominations it appears that the colours of the above-mentioned ſpectrum are ſeven; but an unprejudiced ſpectator will find it difficult to determine their number. Sir Iſaac Newton reckoned them

them ſeven in number, and conſidered the intermediate ſhades as heterogeneous colours, or mixtures of ſome of the ſeven [*]. Nollet thought there was reaſon to conclude that the orange, the green, and the indigo, are the three ſimple, or homogeneous colours [†]. Some perſons have acknowledged five primitive colours. Others, obſerving that all ſorts of colours may apparently be formed by mixtures of red, yellow, and blue, in due proportions, have admitted thoſe only as primitive, homogeneous, or uncompoſed colours. However, certain facts and obſervations, which will be mentioned in the ſequel, are very much in favour of Newton's theory.

Various methods have been tried for the purpoſe of rendering the colours of the ſpectrum diſtinct or unmixed with each other; but none, as yet, has been attended with a complete effect. The following method ſeems to be the beſt approximation.

Let the light of the ſun paſs through a hole of about one tenth of an inch, into a dark room, and placing a ſcreen at a little diſtance (for inſtance ſix inches) within the room, let the middlemoſt part of that light paſs through a ſimilar hole in the ſcreen; the object of which is to prevent in great meaſure the indefinite light or penumbra on the

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[*] See his Optics.

[†] *Leçon de Phyſique, tome* V. *p.* 388. See alſo D'Alembert's *Opuſc. Mathem. tome* III. *p.* 393. Rochon's *Recher. ſur la Nature de la Lumiere des Etoiles fixes.*

ſides of the ſpectrum. Let that light fall perpendicularly upon a convex lens, at the diſtance of about 10 feet, by which means an image well defined of the ſun will be formed upon a ſcreen placed at a proper diſtance from the lens: but if a priſm be placed cloſe to the lens, ſo that the light, after having paſſed through the lens, may paſs through, and be refracted by, the priſm; then a coloured ſpectrum will be formed upon the ſcreen, fig. 12. Plate XX.

The long ſides of this ſpectrum are very well defined. Its narrow terminations are ſemicircular, and its whole length conſiſts of circular coloured images of the ſun, which are intermixed with each other, eſpecially about the middle or axis of the ſpectrum; yet the moſt predominant colours are more diſtinguiſhable from each other, eſpecially towards the ſides of the ſpectrum, ſo that their boundaries may be marked with tolerable accuracy*.

Fig. 7. Plate XX. repreſents ſuch a ſpectrum, and the lines F M, *ba*, *dc*, *fe*, *hg*, &c. are drawn through the centres of the principal circles belonging to the ſeven principal colours. The ſpaces, which thoſe ſeveral colours occupy, are not equal.

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* For this purpoſe the priſm and the lens muſt be well formed, and as free from veins, bubbles, ſcratches, &c. as poſſible. Every other part of the operation muſt alſo be conducted with great accuracy, excluding every other light from the room, &c.

If

If the length of the ſpectrum, from I to M, be divided into 360 equal parts, then the red colour will be found to occupy the ſpace MF *b a*, the length of which, M *a*, is equal to 45 of thoſe parts; the length *a c* of the orange, *a b d c*, will be found equal to 27 of thoſe parts; the length *c e* of the yellow equal to 48; that of the green to 60, that of the blue to 60, that of the indigo to 40, and, laſtly, the length *l* I of the violet, *l m n* I, equal to 80 of thoſe parts.

It is very remarkable that by thoſe diviſions, *a*, *c*, *e*, *g*, *i*, *l*, I, the line IM is divided very nearly like a muſical chord. Let the ſide IM of the ſpectrum be produced, ſo as to make MX equal to IM; then *l* X will be found to be 8-9ths of IX; *i* X will be found to be 5-6ths of IX; *g* X to be 3-4ths, *e* X to be 2-3ds, *c* X to be 3-5ths, *a* X to be 9-16ths, and MX to be one half of IX: ſo that if IX were a muſical ſtring, like a violin ſtring, and expreſſed a certain muſical tone, for inſtance C, then the length *l* X would expreſs D, or the ſecond; *i* X would expreſs E flat, or flat third; *g* X would expreſs F, or fourth; *e* X would expreſs G, or fifth; *c* X would expreſs A, or ſixth ſharp; *a* X would expreſs B flat, or flat ſeventh; and MX would expreſs C, or the octave. But it muſt be remarked, that the diviſions of the colours of the ſpectrum cannot be obtained with great accuracy; and even if they could always be obtained preciſely as the above, which are exactly as were originally given by Sir Iſaac Newton *; yet the arrangement of the muſical notes, correſpondent with thoſe diviſions, is by no means regular; a flat third with a ſharp ſixth and a flat ſeventh being inadmiſſible in an octave of muſical notes.

It is evident that white light conſiſts of coloured rays, which have different but peculiar refrangibilities; the red being the leaſt, and the violet the moſt refrangible †. The following experiments will illuſtrate and confirm this theory.

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* Optics, B. I. Part II. Experiment VII.

† It has been ſaid above, that the ſine of incidence is to the ſine of refraction from air into glaſs, nearly as 3 to 2; therefore by inverting the analogy, the ſine of incidence is to the ſine of refraction from glaſs into air, as 2 to 3. Now, if the priſm in fig. 4. be turned round its axis, ſo that the beam of light C O may fall perpendicularly upon the ſide D O, then that beam will not ſuffer any refraction from C to E; but as it falls obliquely upon the ſide D E of the priſm, it will, on going out from the glaſs into the air at E, ſuffer a refraction. Now when the ſine of the angle of incidence of the beam C O E, upon the ſide D E, was equal to 50, Sir Iſaac Newton found that the ſine of refraction for the red rays, or extreme part E G of the ſpectrum, was 77, and the ſine of refraction for the violet or extreme part E H of the ſpectrum, was 78. Therefore, dividing the difference between 77 and 78, in the ſame proportion as the ſpectrum A G F M, fig. 7. is divided, he obtained the following ſines for the boundaries of the ſeven different colours, viz. 77, 77 $\frac{1}{8}$, 77 $\frac{1}{5}$, 77 $\frac{1}{3}$, 77 $\frac{1}{2}$, 77 $\frac{2}{3}$, 77 $\frac{7}{9}$, 78; that is, the ſines of the red rays are between 77 and 77 $\frac{1}{8}$; thoſe of the orange rays are between 77 $\frac{1}{8}$, and 77 $\frac{1}{5}$, &c.

After

After having received a beam of light upon a priſm SVT, Fig. 5. Plate XX. place, at ſome diſtance from the priſm, two ſcreens or boards, PQ, *pq*, each perforated with a ſmall hole X, *x*; and beyond the ſcreen *pq* place a ſecond priſm *svt*, in the ſituation indicated by the figure. The refracted light will form the uſual ſpectrum upon the ſcreen PQ. Now, if by turning the priſm SVT gently about its axis, you let the rays of the different colours paſs ſucceſſively through the two holes X, *x*, and through the priſm *svt*, you will perceive a circular image of the ſun upon the wall or ſcreen Y*y*, changing colour according to the ray which produces it, and likewiſe changing place; viz. when the image is red, its place will be, for inſtance, Z; but when yellow, its place will be higher than Z; when green, its place will be higher ſtill, and ſo on; for the yellow rays are more refrangible, viz. are bent more by the priſm than the red, the green more than the yellow, &c.

If the light which has been refracted and diſperſed by a priſm, be received again upon another priſm AB, Fig. 6. which muſt be ſituated in a direction perpendicular to that of the former; the ſpectrum will by that means be removed from its original ſituation MN, into the inclined ſituation ZY, but its breadth and its colours will remain unaltered. Now if the elongation of the beam of white light and its reſolution into different colours, were a modification of light produced by the priſm only, then

then the ſecond priſm AB ought to expand the ſpectrum in breadth, ſo as to form the quadrilateral broad figure Z *m* Y *n*; but inſtead of that we find that the colours and their breadths remain unaltered; the ſpectrum has only been removed from the original ſituation MN, by the refractive power of the priſm, and the violet rays have been removed moſt, viz. from M to Z, becauſe they are moſt refrangible, the red rays have been removed leaſt, viz. from N to Y, becauſe they are leaſt refrangible, and the other colours come in order between thoſe extremes.

If the refracted and diſperſed beam of ſolar light be received upon a concave reflector CD, Fig. 8. Plate XX. the differently coloured rays will be reflected to a focus A, where they will form a white or colourleſs image of the ſun; but if any of the colours be ſtopped by interpoſing a wire or ſome other opaque and ſlender body between the priſm and the reflector, as at B, then the image A will become coloured with ſome mixt colour. This proves that white light conſiſts of coloured rays intermixed in a certain proportion; and that by a mixture of the rays of the ſeven primary colours in that due proportion, white light is produced. Therefore white ariſes from a certain mixture of colours, and blackneſs ariſes from a ſtoppage or abſorption of all colours. Beyond the focus A, the rays are ſeparated again, and the image is coloured.

If, when a ſpectrum is formed by the light which has paſſed through a priſm upon a ſcreen, a ſmall hole be made through the ſcreen, and the rays of one colour only be permitted to paſs through it on the other ſide of the ſcreen; then whatever is viewed in that homogeneous light will appear of that particular colour. Thus, if the red light only has paſſed through the hole, then blood, or graſs, or milk, &c. viewed in that light behind the ſcreen, will all appear red, excepting that the blood will appear a ſtronger red than the graſs and the milk. If the blue light only has been tranſmitted through the hole, then the above-mentioned three ſubſtances will all appear blue; and the like thing muſt be underſtood with reſpect to the other colours.

If this homogeneal light behind the ſcreen be received upon another priſm, it will be refracted, viz. bent, but not diſperſed by it, ſo that it will form a circular ſpot of one uniform colour upon the ſcreen.

If two holes at about a foot diſtance from each other be made in the ſhutter of a dark room, and two priſms, viz. one be placed to receive the light at each of thoſe holes, two ſpectrums will thereby be formed upon the ſcreen; and by turning the priſms gently round their axes, the ſpectrums may be cauſed to fall one upon the other. Let the yellow of one ſpectrum fall upon the blue of the other, and at that place the mixture of thoſe two colours will

will produce a green. Let a ſmall hole be made exactly at that place, and that green colour will paſs through it behind the ſcreen, and will form a green circular image upon another ſcreen placed to receive it. Now, if exactly behind the perforation of the firſt ſcreen you fix the refracting angle of a priſm, then the image upon the ſecond ſcreen will not only be moved from its place, but will appear oblong with a yellow border on one extremity, and a blue border on the other extremity; becauſe that ſpot or image conſiſts of two primitive colours of different refrangibilities. The ſame thing muſt be underſtood of any other colour formed from a mixture of two primitive priſmatic colours; for any two of thoſe colours will form, or rather look like, an intermediate colour; thus red and yellow form an orange, blue and violet form an indigo, &c.

If the ſame experiment be performed with one ſolar ſpectrum, viz. a ſingle priſmatic colour be permitted to paſs through a hole in the ſcreen, and then be received upon another ſcreen, the image will be of the ſame colour, for inſtance, green, and circular. Now, by placing a priſm behind the perforation of the firſt ſcreen, the green image will be moved from its place, but will not be elongated, nor altered in colour, becauſe that image conſiſts of one uniform primitive colour *.

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* Newton's Optics, B. I. Part II. Prop. IV.

This ſhews, that though green may be formed of two colours, or any other priſmatic colour may be formed from two other colours, yet each of thoſe colours in the priſmatic ſpectrum is a primitive, uniform or homogeneous colour.

When a perſon looks at any object through a priſm, that object, eſpecially if it be a white one, and well illuminated, will appear bordered with colours at top and bottom; the reaſon of which is, that the colours of the light which comes from the object, are refracted by the priſm, and more or leſs according to their different refrangibilities: hence not only the whole image will appear in a place different from the real direction; but the blue indigo and violet colours will be removed more than the red, orange, &c. Thus, if an eye O, Fig. 9. Plate XX. looks through the priſm P, at a piece of white paper A B, that paper, which would appear white, and at its real place without the priſm, will, when the priſm is interpoſed, appear elevated to the place CE, alſo elongated, and terminated by coloured fringes at top and bottom; the blue indigo and violet being at top, and the red, orange, and yellow at the bottom; for, in truth, the priſm, by refracting the different colours differently, forms ſeven images of the paper, of which the violet image is the higheſt, the indigo next, then the blue, the green, the yellow, the orange, and loweſt of all is the red image; the red rays being the leaſt refrangible. Now it is eaſy to perceive, that all thoſe

thoſe images are intermixed towards the middle *g h i m*, where of courſe the paper appears white; but they begin to be leſs mixed towards *i m* and *g h*, where of courſe the colours begin to appear, &c.

It is neceſſary to mention in this place an obſervation concerning the reflection of light, which could not have been well explained previous to the theory of the different refrangibilities of coloured rays; for this purpoſe we muſt alſo premiſe a uſeful practical method of tracing a ray of light through a priſm, or in general through any refracting medium.

Let H I K, Fig. 10. Plate XX. repreſent a glaſs priſm, whoſe angle at H is equal to 60°, and A B a ray of light, which coming through a narrow tube A, falls upon the ſide of the priſm at B. Draw L B G perpendicular to the ſurface of the priſm at B, then A B L will be the angle of incidence, which we ſhall ſuppoſe equal to 38°. Find in the trigonometrical tables, the ſine of 38°, which is 61566; then, becauſe the ſine of incidence is to that of refraction from air into glaſs, as 3 to 2*, ſay, as 3 is to

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* In this place we have adopted the ratio of 3 to 2, for the ſake of avoiding fractions; but it is evident that any other ratio may be uſed; and in practice the ratio of the ſine of incidence to that of refraction for any particular ſubſtance muſt be taken from the table in page 176; and when accuracy is required, the ratio for any particular coloured ray of light may be deduced from the diſperſive property of the ſubſtance in queſtion, which is obtained from the ſame table, and from what has been ſaid in page 184.

to 2, ſo is 61566 to a fourth proportional, viz. to 41044, which is the ſine of 24°, 14′ (as appears from the trigonometrical tables); therefore make the angle G B C equal to 24°, 14′, and B C is the courſe of the beam of refracted light through the priſm. Produce B C until it meets the ſide of the priſm at C, and through C draw the perpendicular F C E to the ſurface of the priſm; then F C B is the angle of incidence upon that ſurface, which being meaſured, will be found equal (ſince the angle at H is equal to 60°) to 35°, 46′, and its ſine (being found in the table) is 58449. Now, ſince the ſine of the angle of incidence is to that of refraction from air into glaſs as 3 to 2; therefore, from glaſs into air, it is as 2 to 3: hence you muſt ſay, as 2 is to 3, ſo is the ſine of F C B, viz. 58449, to a fourth proportional, viz. to 87673, which in the table will be found to be the ſine of 61°, 15′. Therefore, if you make the angle E C D of 61°, 15′, C D will be the mean courſe of the ray of light after it has paſſed through the priſm.

This method is evidently applicable to glaſſes, or other tranſparent mediums, of any given form.

The phenomenon reſpecting the reflection of light, which we promiſed to mention, is, that when rays of light proceed through a medium, which is ſurrounded by a thinner, or rather by a leſs refractive medium, and if it impinges upon the ſurface at a great angle of incidence, viz. much inclined to that ſurface, then thoſe rays will not paſs into

into the thinner medium, but will be reflected from the ſurface of the denſer medium. And the moſt refrangible rays, viz. the violet, indigo, &c. will be found to be the moſt reflexible, and *vice verſa.*—The following illuſtration will ſhew the meaning and the reaſon of the aſſertion.

Let a beam of light, coming from an hole at A, Fig. 11. Plate XX. fall perpendicularly, or nearly ſo, upon the ſide E D of a glaſs priſm, in which caſe the beam of light will not be refracted, but will proceed ſtraight into the glaſs, and will fall upon the ſurface or boundary G D, between the glaſs priſm and the air. Now if the angle of inclination B C D be ſmaller than about 49°, or, which comes to the ſame thing, if the angle of incidence O C B be greater than about 41°, then the beam of light A B C, inſtead of paſſing out of the priſm at C into the air, will be reflected towards C F. Suppoſe, for inſtance, that the angle of incidence B C O is 56°, its ſine will be 82920; then ſay, as 2 is to 3, ſo is 82920 to a fourth proportional, viz. to 124380, which exceeds the radius or ſine of a right angle; therefore the angle of refraction PCH muſt be greater than a right angle, viz. the beam of light cannot come out of the ſurface G D, but muſt be reflected towards F, and that is the caſe whenever the ſine of refraction exceeds the radius.

By turning the priſm gently round its axis, it will be found that whilſt the angle B C O is leſs than 41°, all the light will paſs out of the priſm at C; but by increaſing that angle ſtill farther, you will find that the violet rays will begin to be reflected firſt, whilſt the others paſs through, then the indigo rays will be reflected, &c. and laſt of all the red rays will be reflected; becauſe the ratio of the ſine of incidence to that of refraction is greateſt for the violet rays, and leaſt for the red rays.

The different refractive, and different diſperſive powers of the various tranſparent mediums, which at firſt ſight might be conſidered as an imperfection of great obſtruction to the improvement of practical optics, have, on the contrary, been the means of improving certain optical inſtruments to a very conſiderable degree. The immediate application of the principles to the conſtruction of thoſe inſtruments will be explained in a ſubſequent chapter; but we ſhall in the preſent chapter endeavour to explain the principles upon which it depends.

The principal uſe of moſt of the optical inſtruments is to render objects more perceptible to our eyes than they are without their aſſiſtance; and that end is in general obtained by bending (viz. refracting) the rays of light, ſo that a greater quantity of thoſe, which iſſue from any given object, may enter our eyes, and may alſo form a larger viſual angle. But by the bending, or the refraction, light is ſeparated into coloured rays; therefore the objects which are viewed by any refracted light, muſt appear coloured irregularly and differently from what they really are. And this, ſtrictly ſpeaking, is actually the caſe; yet when the light is not much refracted, the diſperſion or ſeparation of colours is ſo trifling, that the eye takes no notice of it, or ſuffers it without inconvenience. But when the light is much refracted, then the diſperſion of colours becomes hurtful and unpleaſant.

Now a method has been contrived (from the various refractive and diſperſive powers of tranſparent mediums, and eſpecially of crown glaſs and flint glaſs) of preventing the diſperſion at the ſame time that the rays are bent or refracted. The following paragraphs will ſhew in what manner this effect can be produced by a combination of refracting mediums.

The reader is requeſted to recollect, 1ſt, that different tranſparent mediums have different refractive powers; 2dly, that they have different diſperſive powers; and 3dly, that in the ſame medium the angle of diſperſion becomes larger or ſmaller, according as the angle of refraction is increaſed or diminiſhed.

Let A B C, fig. 13. Plate xx. be a priſm of crown glaſs, and D E a beam of light falling upon it, which, by paſſing through the priſm, is diſperſed into the coloured pencil F G I. If another priſm, in every reſpect equal to the former, were placed cloſe to it, but in a contrary poſition, ſuch as is indicated by the dotted repreſentation B K C; then this ſecond priſm would undo what has been done by the firſt, viz. the rays ſeparated and bent by the firſt, would be collected and bent the other way by the ſecond; ſo that the beam of light would emerge out of the ſecond priſm in a direction parallel to DE, and without being altered in colour. But if the ſecond priſm have a different refractive and a different diſperſive power, then, notwithſtanding the equality of the figure of the priſms, the beam of light, after having paſſed through both, would emerge both bent and coloured, becauſe the ſecond priſm cannot exactly counteract the effect of the firſt.

Now, by altering the refractive angle of the ſecond priſm, viz. by making it larger or ſmaller, the angle of refraction, and of courſe the angle of diſperſion, may be increaſed or diminiſhed. If the quantity of diſperſion in the ſecond priſm be rendered equal to the angle of diſperſion in the firſt priſm, then the ray of light will emerge without any alteration of colour, but its direction will be inclined to its original direction D E, by as much as the refraction of one priſm exceeds that of the other. This is called the *achromatic refraction* *.

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* Hence we have the *achromatic teleſcope*, viz. a teleſcope which does not alter the natural colours of the objects that are ſeen through it; whereas other teleſcopes with glaſſes generally introduce the priſmatic colours, eſpecially about the edge of the field of view.

On the contrary, if the refraction of one priſm be rendered equal to that of the other priſm, then the beam of light will emerge with its mean direction parallel to DE, but it will be coloured, or ſeparated, by as much as the diſperſive power of one priſm exceeds that of the other priſm.

The attentive reader may eaſily comprehend, that either of the above-mentioned effects may alſo be produced by a combination of three or more priſms *.

Having explained the principal properties of the regular refracting mediums, it might perhaps be expected that an account of thoſe ſubſtances which have a double, or multiple refracting power,

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* A beam of ſolar light, refracted by paſſing through a priſm of crown glaſs, the refracting angle of which is 30°, when the ray of mean refrangibility paſſes, or enters and emerges, at an equal diſtance from the vertex of the priſm, the angle of diſſipation will be about 39′.

If a priſm of flint glaſs, whoſe refracting angle is 23°, 40′, be adapted in an inverted poſition, as in fig. 14. Plate xx. to a priſm of crown glaſs, whoſe refracting angle is 25°; a beam of ſolar light will emerge at A, with its mean direction parallel to DE, viz. it will paſs ſtraight, but it will be coloured or diſperſed.

But if to thoſe you add a third priſm of crown glaſs, the refracting angle of which is 10°, as in fig. 15. Plate xx. then the emergent beam of ſolar light will deviate by about 5°, 37′, from the courſe of its incident part DE, but it will not be altered in colour, viz. it will be white, as it was before it entered the combination of priſms.

among which the Iſland cryſtal is the moſt diſtinguiſhed, would be ſubjoined: but the equivocal nature of thoſe ſubſtances, the unknown cauſe of their effects, and the little uſe which is made of them, have induced me to employ the following pages for more uſeful purpoſes, and to refer the inquiſitive reader to the works of other authors *.

With reſpect to the priſmatic colours ſeparately conſidered, it may be obviouſly obſerved, that ſome of them affect our eyes more powerfully than others; or in other words, that objects in general may be ſeen much better in ſome of them than in others; yet the preciſe order with reſpect to their peculiar illuminating power, cannot be determined without a conſiderable number of accurate obſervations.

For this purpoſe a priſmatic colour muſt be ſeparated from the ſolar ſpectrum, viz. by permitting it to paſs through a hole in the ſcreen, upon which the ſpectrum is projected by the priſm, and objects muſt be viewed in that homogeneous light behind the ſcreen, then the ſame objects muſt be viewed in another homogeneous light, and ſo on.

Dr. Herſchel, who, as far as I know, has made the moſt recent experiments upon this ſubject, after the account of thoſe experiments, expreſſes himſelf in the following manner:

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* Prieſtley's Hiſtory of Viſion, Light, and Colours. Period VI. Sect. VIII.

"From theſe obſervations, which agree uncommonly well, with reſpect to the illuminating "power aſſigned to each colour, we may conclude, "that the red-making rays are very far from having "it in any eminent degree. The orange poſſeſs "more of it than the red; and the yellow rays illuminate objects ſtill more perfectly. The maximum of illumination lies in the brighteſt yellow, "or paleſt green. The green itſelf is nearly "equally bright with the yellow; but, from the "full deep green, the illuminating power decreaſes "very ſenſibly. That of the blue is nearly upon "a par with that of the red; the indigo has much "leſs than the blue; and the violet is very deficient*."

I ſhall conclude this Chapter on Refraction, by obſerving, that beſides the method in the preceding page, viz. by the priſms ſimply uſed, the refractive powers of tranſparent mediums may alſo be determined by other means, as by meaſuring the focal diſtances of lenſes when they tranſmit the rays of different colours ſucceſſively; by employing other inſtruments in conjunction with the priſms, &c.†

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* Philoſophical Tranſactions for 1800, page 267.

† See the deſcriptions of thoſe methods in Prieſtley's Hiſtory of Viſion, &c. Period V. Sect. VIII. Chap. II. Martin's Optics; Rochon's *Recueil de Mem. ſur la Mecan. et la Phyſique*; *Mem. ſur la Meſure de la Diſperſion, et de la Refraction*, &c.

CHAPTER IV.

OF THE INFLECTION OF LIGHT, THE COLOURS OF THIN TRANSPARENT BODIES, AND OF COLOURS IN GENERAL.

LIGHT, in paſſing within a certain diſtance of the ſurface of bodies, is bent ſo as to form apparently a rectilinear angle at that place. Thus if a ſmall hole be made in the ſhutter of a window of a darkened room, and the light of the ſun be permitted to paſs through it, the image of the ſun, or white ſpot which is formed upon a ſcreen placed to receive that light in the room, will be found to be larger than it ought to be if right-lined rays proceeded from the various points of the ſun's ſurface, and paſſed through the hole to the ſcreen; hence it appears that they are bent at the hole; for otherwiſe the image would be ſmaller than experience ſhews it to be.

If a ſolid opaque body, ſuch as a hair, a ſlender wire, &c. be placed in the ſtream of light within the room, the ſize of the ſhadow of that body will be found different from what it ought to be if the rays of light were not bent in paſſing by it. This bending of the rays of light by paſſing not through, but near the ſurface of a body, is called the *inflection of light*. It has alſo been called *diffraction*.

The phenomena, which relate to this ſubject, not appearing to be reducible to one general principle, were particularly examined under a conſiderable variety of circumſtances by Sir Iſaac Newton; yet his obſervations were not quite correct; nor was his hypothetical explanation very plauſible.

Subſequent experiments and obſervations ſeem to reduce the phenomena of inflection to a ſingle principle, namely, to the attraction of bodies towards light, which attraction becomes conſpicuous when the rays of light paſs within a certain diſtance of their ſurfaces. Beſides their being bent, the rays of light are likewiſe ſeparated into colours by the vicinity of bodies, and this produces the ſingular phenomenon of the coloured fringes that accompany the inflections. But previous to the application of the hypotheſis, it will be proper to deſcribe the principal phenomena of the inflection of light, and for this purpoſe I ſhall prefer the experiments of a recent anonimous writer, which appear to have been inſtituted with judgment and accuracy *.

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* Obſervations concerning the Inflections of Light, &c. London 1799.

" In fig. 16. Plate xx. let X be the hole (about the 50th part of an inch) of the light's paſſage into a darkened room, and let X A, X B, be lines drawn from each external oppoſite edge on one ſide of the ſolar diſc, to each external oppoſite edge on the contrary ſide of the hole, croſſing one another: X C D will repreſent the beam of light after its paſſage through the hole, at all diſtances therefrom, conſiderably larger than the penumbral cone E A B.

" At ſeven feet from the hole the breadth of the beam was $\frac{48}{50}$ parts of an inch. If the light had not been bent, that breadth could not have exceeded $\frac{37}{50}$. Hence it muſt be concluded, that the light being attracted by the ſides of the hole, is inflected, and of courſe cauſed to proceed more divergingly than otherwiſe it would have done.

" With a hole one-tenth of an inch wide, or wider, the centre of the beam was compoſed of the denſe direct light of the ſun, unchanged in its paſſage; but farther therefrom, towards the borders of the beam, this light began to decreaſe in denſity, and gradually decayed more and more in the approaches nearer and nearer to the borders, becoming at laſt conſiderably diluted and evaneſcent, and rendering the edge of the beam ill-defined and indiſtinct.

" With a ſmaller hole than the laſt, the central denſe light entirely diſappeared, and with a hole yet ſmaller than this, the external edges of the beam became more condenſed and better defined; and the whole beam of light became, as before deſcribed, of more uniform denſity in all its parts. With a hole ſmaller than any of the foregoing, about $\frac{1}{100}$ part of an inch wide, various colours began to appear in the beam, the central parts of which became now, in their turn, more diluted than the reſt, the external parts denſer than theſe, and bordered with tinges of yellow and red light on the very edge or margin of the beam.

" All theſe appearances are to be aſcribed to the ſame attractions of the edges of the holes, and of the different parts of the edges. Theſe, when the hole is large, affect only the parts of the light paſſing neareſt to them; when the hole is reduced, they attract and dilate the whole of the paſſing light; when the hole is yet more conſiderably diminiſhed, they act, not only each part upon the light paſſing neareſt to each, but each part alſo upon the light paſſing neareſt to each oppoſite part of the edge, condenſing by diminiſhing the attraction and diffuſion of the light on the edges of the beam, and rendering the whole more equably and uniformly divergent, and theſe at laſt, when the hole is in its moſt reduced ſtate of about $\frac{1}{100}$ part of an inch wide, by their various actions produce colours in the paſſing light.

" In the beam of ſolar light paſſing through the ſmall hole $\frac{1}{50}$ part of an inch wide, I obſerved the ſhadows of very ſlender bodies, pins, needles, ſtraws, hairs

hairs to be conſiderably broader, as they ought to be in this divergent light, than the bodies themſelves; but as each of theſe bodies exerciſes upon the light paſſing by it, the ſame attractions by which the light is bent in paſſing through the hole, I concluded that a part of the light would be in every caſe bent, in paſſing by, towards the body into the ſhadow, and illuminate it and diminiſh its breadth.

" Acroſs a beam of ſolar light, admitted into a dark chamber through a ſmall hole in a thin piece of lead, nearly $\frac{1}{50}$ of an inch wide, I interpoſed a hair of a man's head, and receiving the beam on a ſcreen or ſheet of white paper at a diſtance, and with an obliquity convenient for the purpoſe, I noted the following appearances.

" At the termination of what may be conſidered as, and therefore may be called, a ſhadow, whoſe intenſity or darkneſs was not conſiderable, the following orders and diſtinctions of colours appeared. Firſt and neareſt to the dark or black parts of the ſhadow might be ſeen a diluted blue, changing into a breadth of white light, followed by breadths of yellow and red. To theſe ſucceeded an interval of diluted ſhade, then breadths of diluted violet, blue, diluted green, yellow, red; then green, diluted yellow, red; diluted green, red; white, diluted red; and finally, white light. Theſe are the more general orders of the colours. Of theſe orders, the three firſt were ſufficiently obvious and diſtinct;

the laſt evaneſcent and requiring accommodation of circumſtances to produce, and attention to perceive them.

"When the diſtance of obſervation from the hair was very ſmall, and before the firſt bright ſtreak of light began to appear, the ſhadow of the hair was diſtinct and well-defined, and of intenſe blackneſs. At a greater diſtance, this ſhadow appeared to be divided by a parallel line of light throughout its whole length, into two parts, and reſembled a double ſhadow, or the ſhadows of two hairs, but was by no means of the ſame degree of blackneſs as was the ſingle ſhadow obſerved cloſe to the hair. At ſtill greater diſtances, it increaſed in breadth and diminiſhed in blackneſs, whilſt the tranſverſe dimenſions of the dividing line of light increaſed at the ſame time, until, at a conſiderable diſtance from the hair, this intermediate band or line of light began to put on the appearance of colours on its edges, and to aſſume, on both ſides externally, caſts of yellowiſh and reddiſh light. By further increaſe of diſtance, this apparent ſhadow, theſe dark intervals became more diluted, and of nearly the ſame colour throughout, the line of light more and more diffuſed, and was at laſt extinguiſhed by the extreme diffuſion and ultimate inviſibility of the light that produced it.

"Whilſt at all theſe different diſtances theſe changes proceed in the ſhadow, and in the light neareſt to the body, in the other adjoining parts of the

the light paſſing next in order of diſtance by the hair, conſiderable changes alſo are produced.

" The ſhadow that firſt appeared cloſe to the hair is perfectly and truly a ſhadow, being produced by the interception of the paſſing light by the hair.

" This ſhadow, however, quickly ceaſes to appear, the rays of light neareſt to it on both ſides of the hair being bent into it at conſiderable angles of inflection and diſperſion, and croſſing, illuminating and extinguiſhing it.

" The rays of light are not only bent, they are alſo diſtributed or divided into different rays of different colours, in angles of diſperſion greater as the diſtances are leſs, and leſs as the diſtances are greater, in ſuch a manner, that of different colours at the ſame diſtance, the purples, blues, greens, yellows, and reds, are bent towards the body; the purples moſt, each of the others in due ſucceſſion leſs, and the reds leaſt, according to the order of their ſtatement, and of colours of the ſame ſorts at different diſtances, the nearer more than the more remote, and the more remote leſs than the nearer. So various, however, are the bendings of different colours at different diſtances, that in certain diſtinct portions of light, and at different diſtances of obſervation, the more remote and the nearer rays of different colours contained within each of thoſe portions or diviſions of the light, become variouſly intermingled with each other,

other, and by their various intermixtures, form each of theſe diviſions into particoloured fringes, whilſt the rays of different diviſions, never mixing with thoſe of other diviſions, the intervals of the diviſions are preſerved, and become the dark intervals which ſeparate the fringes."

I have tranſcribed the above paſſages principally to give the reader an idea of the inflection of light in a few eaſy and conſpicuous experiments; but theſe are not all the phenomena of inflection, nor is the ſame explanation entirely new or applicable to them all. Beſides Newton, various experiments were made relative to the inflection of light by Maraldi, Grimaldi, Deliſle, Mairan, Du Tour, Muſchenbroeck, and others; an account of which experiments the reader may ſee in Prieſtley's Hiſtory of Viſion, Light, and Colours*.

Thin plates of tranſparent bodies, eſpecially when they are not of an uniform thickneſs, frequently exhibit the principal priſmatic colours (viz. ſuch colours as are exhibited by the refraction of light through a priſm) either in rings, or zones, or mixt.

All the phenomena which have been obſerved relative to theſe colours, are by no means reconcilable to any known and determinate laws; therefore all the obſervations ſhould be ſingly and duly

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* Part VI. Sect. VI.

conſidered by whoever wiſhes to inveſtigate the nature of thoſe phenomena, or to diſcover new facts. We ſhall however only give the following ſummary account.

The colours that are ſeen on the bubbles of impure water, and eſpecially of a ſolution of ſoap, are of this ſort. Thoſe bubbles are thin veſicles or films of the ſolution, and are continually varying in thickneſs.

When two flat glaſſes, and eſpecially when one which is a little convex, and a flat one, are gently preſſed together, coloured rings are frequently viſible about the point or points of contact; which have been ſuppoſed to be produced by the thin film of air that remains between the glaſſes, and which is of various thickneſs; yet thoſe colours are viſible even when the glaſſes are under the exhauſted receiver of the air-pump.

Metallic plates, glaſſes, &c. ſlightly moiſtened with moſt liquors, frequently exhibit ſuch colours. Thin plates of talk, or Muſcovy glaſs, do the ſame.

The cauſe of thoſe phenomena has been attributed by Newton to certain diſpoſitions of the rays of light, which he called *fits of eaſy tranſmiſſion and of eaſy reflection*, — a ſtrange hypotheſis. Other perſons have attributed it to refraction or to reflection only: the duke de Chaulnes attributed ſome of thoſe effects to the inflection of the rays; and

and a recent anonimous writer has adopted and extended the ſame idea *.

In order to give my readers a competent idea of thoſe phenomena, I ſhall ſubjoin a few of the moſt ſtriking facts.

Sir Iſaac Newton took the object glaſſes of two teleſcopes, one a plano-convex for a teleſcope of 14, and the other a double convex for a teleſcope of about 50 feet, laid the latter upon the flat ſide of the former, and preſſed them gently againſt each other. Circles of colours immediately appeared about the point of contact, which increaſed in number and in ſize when the preſſure was increaſed, and *vice verſa.* The colours appear more vivid nearer to the central ſpot, which is black and colourleſs, and more dilute in proportion as they recede from it. When the glaſſes were very much preſſed againſt each other, Sir Iſaac found the coloured circles to be of unequal breadths, as in fig. 17. Plate xx. where the letters *a*, *b*, *c*, *d*, *e*, *f*, &c. indicate the colours in the following order, which commences from the centre *a*. Black, blue, white, yellow, red; violet, blue, green, yellow, red; purple, blue, green, yellow, red; green, red; greeniſh blue, red; greeniſh blue, pale red; greeniſh blue, rediſh white †.

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[*] See Prieſtley's Hiſtory of Viſion, Light, and Colours, P. VI. Sect. V. Alſo, New Obſervations concerning the Colours of thin tranſparent Bodies, &c. London 1800.

[†] Newton's Optics, B. II. P. I. Obſerv. IV.

" The Abbé Mazeas obſerved, that if the ſurfaces of flat pieces of glaſs be tranſparent, and well poliſhed, ſuch as are uſed for mirrors, and the preſſure be as equal as poſſible on every part of the two ſurfaces, a reſiſtance will ſoon be perceived, when one of them is made to ſlide over the other, ſometimes towards the middle, and ſometimes towards the edges; but wherever the reſiſtance is felt, two or three very fine curve lines will be perceived, ſome of pale red, and others of a faint green. Continuing the friction, theſe red and green lines increaſe in number at the place of contact, the colours being ſometimes mixed without any order, and ſometimes diſpoſed in a regular manner. In the laſt caſe, the coloured lines are generally concentric circles, or ellipſes, or rather ovals, more or leſs elongated, as the ſurfaces are more or leſs united. Theſe figures will not fail to appear if the glaſſes be well wiped and warmed before the friction.

" When the colours are formed, the glaſſes adhere with conſiderable force, and would always continue ſo, without any change in the colours. In the centre of all thoſe ovals, the longer diameter of which generally exceeds ten lines, there appears a ſmall plate of the ſame figure, exactly like a plate of gold, interpoſed between the glaſſes; and in the centre of it there is often a dark ſpot, which abſorbs all the rays of light, except the violet; for this colour appears very vivid through a priſm.

“ If the glaſſes be ſeparated ſuddenly, either by ſliding them horizontally one over another, or by the action of fire, the colours will appear immediately upon their being put together, without the leaſt friction.

“ Beginning by the ſlighteſt touch, and increaſing the preſſure by inſenſible degrees, there firſt appears an oval plate of a faint red, and in the centre of it a ſpot of light green, which enlarges by the preſſure, and becomes a green oval, with a red ſpot in the centre; and this enlarging in its turn, diſcovers a green ſpot in its centre. Thus the red and the green ſucceed one another in turns, aſſuming different ſhades, and having other colours mixed with them.

“ The greateſt difference between theſe colours exhibited between plane ſurfaces and thoſe by curve ones is, that, in the former caſe, preſſure alone will not produce them, except in the caſe abovementioned. With whatever force he compreſſed them, his attempts to produce the colours were in vain, without previous friction. But the reaſon of this plainly was, that without ſliding one of the glaſſes over the other, they could not be brought to approach near enough for the purpoſe.

“ At firſt the Abbè Mazeas had no doubt but that theſe colours were owing to a thin plate of air between the glaſſes, to which Newton has aſcribed them; but the remarkable difference in the circumſtances attending theſe produced by the flat plates, and

and thoſe produced by the object glaſſes of Newton, convinced him that the air was not the cauſe of this appearance. The colours of the flat plates vaniſhed at the approach of flame, but thoſe of the object glaſſes did not. He even heated theſe till that which was next to the flame was cracked by the heat, before he could obſerve the leaſt dilatation of the coloured rings. This difference was not owing to the plane glaſſes being leſs compreſſed than the convex ones; for though the former were compreſſed ever ſo much by a pair of forceps, it did not in the leaſt hinder the effect of the flame *."

The coloured circles, ſuch as have been mentioned above, ſeen by reflected light, are much more vivid and diſtinct than thoſe ſeen by tranſmitted light.

The rings ſeen by reflection generally are differently coloured from thoſe made by tranſmitted light. White in the latter caſe is oppoſed to black in the former, red to blue, yellow to violet, and green to a compound of red and green.

The more obliquely the rings are viewed in either caſe, the larger they appear to be.

When water is cauſed to riſe between the glaſſes, the

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* Prieſtley's Hiſtory of Viſion, Light, and Colours, Part VI. Sect. V. wherein the reader will find a great many other particulars reſpecting thoſe experiments, as alſo ſimilar experiments made by other perſons.

the brightneſs of the colours is thereby much diminiſhed. Alſo the rings contract in number and breadth.

Newton's theory, principally eſtabliſhed upon the above-mentioned phenomena of thin plates, has long been thought to afford a ſufficient explanation of the various colours which are exhibited to our eyes by the different bodies of the world.

According to that theory, all colours are ſuppoſed to exiſt in the light of luminous bodies only, ſuch as the ſun, a candle, &c. and that light, falling inceſſantly upon different bodies, is ſeparated into its primitive colours, ſome of which are abſorbed, whilſt others are inceſſantly reflected; ſo that the bodies which appear red to us, are ſuch as abſorb all the other colours of white light, and reflect the red rays only. Thoſe which appear green to us have the property of abſorbing all the coloured rays, excepting the green. Thoſe bodies which appear not of any primitive colour, have been ſuppoſed to reflect ſuch of the primitive colours, and in ſuch proportion as to produce their mixt colours, &c.

So far the hypotheſis ſeems to be warranted by ſome of the experiments that have been mentioned in the preceding chapter; but the next ſtep is leſs evident, even to the eyes of fancy. It was ſuppoſed that the particles of all bodies conſiſt of very thin and tranſparent plates, or laminæ, which reflect or tranſmit one colour or another, according to their

thickneſs;

thickneſs; that the thinner produce the more vivid colours; and that the colours of ſome plates vary according as the eye changes poſition, whilſt thoſe of others are ſteady and uniform.

A cloſe examination and application of this doctrine to a variety of phenomena, which have been obſerved by various ingenious perſons, eſpecially of the preſent age, render this theory of colours doubtful in almoſt all its parts. In the firſt place, it may be doubted whether there really are only ſeven diſtinct primitive colours, or an indefinite number of them, which are perhaps produced by ſome unknown modifications of white light. The breadths and the gradations of the ſuppoſed ſeven primitive colours in the priſmatic ſpectrum, are the greateſt foundation for the above-mentioned doubt. With reſpect to the thin tranſparent plates, of which all bodies are ſuppoſed to conſiſt, we are greatly in want of experimental confirmation; and even if we were ſure of their exiſtence, it would be difficult thereby to explain how are the fixed and unchangeable colours produced by them in all directions. Such doubts may be ſeen in all the modern writers on optics, to whoſe works, which are principally to be found in Tranſactions of Societies, Journals, &c. I ſhall refer the inquiſitive reader, who may wiſh to be farther informed on the ſubject, or to extend our knowledge of nature; whilſt I ſubjoin ſome more remarkable facts relative to colours.

The changes of colour in the ſame body, which are produced either by poſition, or by a change of quality in the body itſelf, never fail to ſtrike the obſerver with admiration and pleaſure.

With reſpect to the change by poſition, it has been obſerved that certain ſolids, and eſpecially certain fluids, appear of one colour by reflected light, and of another colour by tranſmitted light; the reaſon of which is, that if they reflect all the rays of one or of certain primitive colours, the light, which, by paſſing through them, comes to our eyes, muſt exhibit other colours; for it has been deprived of thoſe colours which have been reflected from the anterior part.

Mr. Boyle obſerves, that if an infuſion of *lignum nephriticum* be put in a glaſs globe, and be expoſed to a ſtrong light, it will be as colourleſs as pure water; but if it be carried into a place a little ſhaded, it will be a moſt beautiful green. In a place ſtill more ſhaded, it will incline to red, and in a very ſhady place, or in an opaque veſſel, it will be green again. If it be held directly between the light and the eye, it will appear tinged (excepting the very top of it, where a ſky coloured circle ſometimes appears) almoſt of a golden colour, except the infuſion be too ſtrong, in which caſe it will be dark or reddiſh, and requires to be diluted with water. But if it be held from the light, ſo that the eye be between the light and the phial, it will appear of a deep lovely blue colour, as will alſo

alſo the drops, if any lie on the outſide of the glaſs.

The changes of colour which are produced by mixtures, by boiling, heating, pounding, &c. are ſo common, and ſo remarkable as to come within every body's notice; but the reaſon of ſuch changes has been differently accounted for by different philoſophers. One of the moſt plauſible theories is, that an attenuation of the particles of a given body changes from the violet, or from ſome colour nearer to the violet, to ſome other colour nearer to the red, in the order of priſmatic colours; and *vice verſa,* the thickning of the particles changes the colours in the contrary order *.

If to the diluted ſyrup of violets you add ſome drops of acid, the liquor becomes red; add a ſmall quantity of carbonated pot-aſh, and it becomes green.

To a ſolution of ſulphate of copper add a few drops of ammoniac, and the liquor becomes blue; add a little nitric acid, and the blue colour vaniſhes.

A vaſt number of ſuch changes is obſerved in chemiſtry, and are ſtated in almoſt all the chemical works †.

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* See Delaval on Colours; alſo ſee his Paper on Colours, in the ſecond volume of Memoirs of the Mancheſter Philoſophical Society.

† See Prieſtley's Hiſtory of Viſion, Light, and Colours, Part VI. Sect. XV.

CHAPTER V.

OF LENSES, AND OF THEIR EFFECTS.

THE refrangibility and reflexibility of light are the properties upon which the conſtruction of the moſt uſeful and moſt ſurpriſing optical inſtruments depends. Of the various parts of the mechaniſms, thoſe which depend upon reflection, viz. the mirrors, have been ſufficiently explained in the preceding pages. It is now neceſſary to enumerate, to deſcribe, and to explain the actions of thoſe which depend upon refraction.

The principal ſhapes of the latter are comprehended under three generic names, viz. *flat plates*, *priſms*, and *lenſes*. The flat plates need no particular deſcription; the priſms have been deſcribed in the preceding chapter; the lenſes will be deſcribed in the preſent.

A thin piece of glaſs, or of any other tranſparent medium, having at leaſt one concave or convex ſpherical ſurface, is called a *lens*. The different forms of lenſes and their peculiar appellations are derived from the figure of their ſurfaces, which may be be either flat, or convex, or concave, or mixt: hence we have ſix ſorts of lenſes, ſections of which are exhibited in fig. 18, Plate XX. and in the order in which they are nominated, viz. the *plano-convex*, the *plano-concave*, the *double convex*, the *double concave*, the *concavo-convex*, and the *meniſcus*, which is likewiſe a concavo-convex, but differs from the preceding by its having the radius of the convexity ſmaller than that of the concavity, in conſequence of which its edges are ſharp, and its ſection reſembles the new moon.

The middle point of each of thoſe lenſes, when the lenſes are thin, is called its *centre*. A ſtraight line paſſing through that centre, and perpendicular to both ſurfaces of the lens, as the line H G is called its *axis*. The points C, D, on the ſurfaces of the lenſes, where the axis cuts the ſurfaces, are called the *vertexes* of the lens. But when the lens is pretty thick, and its ſurfaces of unequal curvatures, then the centre of the lens is nearer to one vertex than to the other, by as much as the radius of curvature of the former ſurface is leſs than that of the other.

It is evident, on the leaſt reflection, that the axis muſt paſs through the centres of convexity or concavity, viz. of the ſpheres of which the ſurface or ſurfaces of the lens are a portion; unleſs the lens be irregularly formed, as in fig. 19, which would be uſeleſs for optical inſtruments, and which is frequently found to be the caſe in practice.

When a ray of light falls perpendicularly upon the vertex of a lens, viz. coincides with the axis HC, it muſt evidently paſs ſtraight through the lens without ſuffering any refraction (ſee page 168 & 171.); but when it falls obliquely upon it, then it muſt emerge out of the lens in a direction inclined to its former direction. Thus of the rays of light, which, iſſuing from the luminous point A, fig. 20, Plate XX. fall upon the lens BE, the ray AC, which proceeds in the direction of the axis of the lens, muſt paſs ſtraight through it; but the ray AB, falling obliquely upon the ſurface of the lens, muſt be refracted, viz. bent; and if the lens be a plano-convex, or double convex, that ray muſt be bent inwardly, viz. towards the axis (as may be traced by means of the method deſcribed in page 190.); conſequently it muſt cut the axis at ſome point F. Now that point F is called the *refracted focus* of that ray, or rather of the rays AB, AE, &c. which fall upon the lens at equal diſtances from the axis AC; it being evident that they muſt all meet and croſs at the ſame point F; whereas the point A is called the *radiant point*, or the *focus of incident rays*; and both thoſe points, in reference to each other, are called the *conjugate foci.*

If the lens be a concave one, as in fig. 21, Pl. XX. then the oblique rays AB, AE, &c. will be bent outwardly, viz. from the axis: in which caſe if you ſuppoſe thoſe refracted rays to be continued backwards until they meet the axis, as at F; then that point F is called the *virtual focus of the refracted rays*, it being in fact the centre of divergency of the rays. In this caſe the conjugate foci are both on the ſame ſide of the lens, viz. the real focus A of incident rays, and the virtual focus F of the refracted rays B G, D O, E S.

If the reader will give himſelf the trouble of tracing the progreſs of all the rays which proceed from a luminous point, and fall upon the ſurface of a lens, be it convex or concave, after the manner which is mentioned in page 190, he will find that the rays will not all meet at one and the ſame focus, if it be a convex lens; nor will they have a common virtual focus, if it be a concave lens; but thoſe rays which are more diſtant from the axis after the refraction, meet ſooner than thoſe which are nearer to the axis; and this effect is greater in proportion as the ſurfaces of the lens are farther from each other, and conſiſt of larger ſpherical ſegments. Hence a glaſs globe renders the abovementioned effect very conſpicuous; and hence are the lenſes made as thin as poſſible; but in all caſes, a lens which conſiſts of ſpherical ſurfaces, does never refract the rays which fall from a luminous point, all to one focus. The rays which fall upon the edge of the lens, have their refracted focus not only nearer to the lens, but alſo fartheſt from the axis, viz. on one ſide of it. Lines drawn through the refracted foci of the rays which belong to one luminous or radiant point, form two curves, which make an angle

angle with each other at the axis, or principal focus, and are called *cauſtics by refraction*; which are real in convex lenſes, but imaginary in concave lenſes.

When the lenſes are thin and their ſphericity not very great, thoſe cauſtics are ſo trifling that the eye does not perceive them; but lenſes that are pretty thick and of great convexity, produce a conſiderable aberration of the rays, and an evident diſtortion of the object, to an eye that looks through them*.

An experimental proof of this aberration may be had in the following manner: cover one ſide of a glaſs globe or thick lens with a circular piece of brown paper, having a row of equidiſtant pin-holes in its diameter. Let the light which paſſes through thoſe holes, and through the lens, fall upon a piece of white paper held perpendicular to the rays of light, and you will find that when the paper is held near to the globe or lens, the ſpots of light upon it are at equal diſtances from one another ſucceſſively; but if the paper be gradually withdrawn from the lens, the intervals between the exterior ſpots grow

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* In order to avoid this aberration, which ariſes from the ſpherical figure of the lens, other figures have been determined, which might refract the light without forming thoſe cauſtics; but the practical difficulty of giving the lenſes any other figure, beſides the ſpherical, is ſo very great, as not to be attempted by any of the opticians.

leſs

leſs than the intervals between the interior, and ſoon unite.

On the other hand, if the ſame operation be performed with a thick concave lens, the intervals between the exterior ſpots will be found to grow larger than the interior, &c.

Beſides the above-mentioned aberration, which ariſes from the figure, lenſes are ſubject to a much greater imperfection, which ariſes from the different refrangibility of the coloured rays; ſo that though the rays which proceed from a luminous point, and fall upon a ſpherical lens at equal diſtances from the axis, would meet or have their focus at the very ſame point, in conſequence of a particular figure of the lens; yet as the refraction ſeparates the light into coloured rays, the violet rays being the moſt refrangible, will form their focus nearer than the blue, and ſo on; the red rays being the leaſt refrangible, will form their focus fartheſt from the lens.

When the lens is thin, and its convexity or concavity not very great, this ſeparation of colours paſſes unperceived; but with a thick lens of great convexity, or when the imperfections of one lens are magnified by another lens, as in teleſcopes and other compound optical inſtruments, the ſeparation of the coloured rays, eſpecially towards the edge, where the refraction is ſtrongeſt, is ſo very manifeſt as greatly to obſtruct the effects which

which thoſe inſtruments would otherwiſe be capable of producing.

This imperfection of lenſes was conſidered as unſurmountable by the great Newton, and all other philoſophers of his time; but the ſubſequent diſcovery of the different diſperſive power of different tranſparent mediums about the middle of the laſt century, made ſome philoſophers entertain hopes of remedying that imperfection of lenſes; and ſoon after the late ingenious Mr. J. Dollond, after a variety of trials and conſiderations, accompliſhed it in the conſtruction of what is now commonly known under the name of *achromatic* (viz. colourleſs) *teleſcope*; the object lens of which is compounded of glaſſes of different diſperſive powers, ſo well proportioned, as not to ſeparate the light into its primitive colours: hence the objects, which are ſeen through it, appear of their natural colours.

Achromatic lenſes for teleſcopes have been made by a combination not only of glaſſes, but alſo of glaſſes and fluids of different diſperſive powers *; yet the common practice is confined merely to glaſſes, which are upon the whole the moſt manageable and the moſt durable ſubſtances.

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* See a paper entitled, *The Principles and Application of a New Method of conſtructing Achromatic Teleſcopes*, by Robert Blair, M. D. in the firſt volume of Nicholſon's Journal of Natural Philoſophy, &c.

Achromatic lenſes are formed either of two lenſes or of three lenſes, fixed in a common cell cloſe to one another. Fig. 22, Plate XX. exhibits a ſection of one of the former, and fig. 23, exhibits a ſection of one of the latter ſort.

In figure 22, AB is a double convex lens of crown glaſs, and CD is a concavo-convex lens of flint glaſs.

In fig. 23, AOB and EF are two double convex lenſes of crown glaſs, the internal lens CD being a double concave of flint glaſs.

The principle upon which thoſe achromatic lenſes are conſtructed may be eaſily derived from what has been ſaid in page 195, where it has been ſhewn, that by a combination of two or three priſms of different ſorts of glaſs, the light which paſſes through them may be refracted without diſperſion; for after the ſame manner the thickneſſes and curvatures of the lenſes may be ſo proportioned as to produce a ſimilar effect. In fact, if we examine a very ſmall portion of ſuch a compound lens, viz. the portion which is contained between the lines *gi*, *hm*, fig. 22, it will appear that the two portions of external lenſes, muſt act like two priſms of crown glaſs, whoſe baſes are towards the common axis of the lenſes; whereas the portion of the middle concave lens acts like a priſm of flint glaſs placed in a contrary direction, viz. with its vertex towards the axis.

Various authors have given intricate methods of determining the curvatures neceſſary for the ſurfaces of thoſe compound lenſes, which are depending upon the refractive and diſperſive properties of the glaſſes, which properties vary greatly; but the difficulty of determining the real diſperſive as well as the real refractive power of a particular ſpecimen of glaſs, which are ſeldom uniform throughout the ſpecimen, and the difficulty of forming the component lenſes exactly of the computed thickneſs and curvature, render thoſe calculations of little uſe in practice. At moſt they ſerve as approximations, which muſt be improved and corrected by actual trials with different glaſſes and different grinding tools*.

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* The following two formulæ for the conſtruction of triple object achromatic lenſes of teleſcopes, are taken from Euler's Dioptrics, vol. I. p. 335.

P is the principal focal length.

The mean refraction from air into crown glaſs, is reckoned as 1,53 to 1.

The ſame out of air into flint glaſs, as 1,58 to 1.

The diſſipating powers of flint and crown glaſs, as 3 to 2.

Firſt Formula.

The radii of the ſurfaces, commencing with the one next to the object, are as follows:

$$\text{A double convex of crown glaſs}\left\{\begin{array}{l}\text{1ſt ſurface} = 0{,}5004 \times P.\\ \text{2d ſurface} = 3{,}6665 \times P.\end{array}\right.$$

A double

An excellent achromatic lens for a teleſcope, made by Dollond, and conſiſting of three lenſes, as in fig. 22, being examined, was found to have the radii of the curvatures of its ſix ſurfaces 1, 2, 3, 4, 5, and 6, of the following dimenſions in inches and decimals. Another ſimilar lens was alſo examined, and the radii, &c. were as in the laſt column.

Firſt ſurface, viz. the external, or next to the object, marked		Radii of the other achromatic object lens, likewiſe in inches, &c.
1	28	28
2	40	35,5
3	20,9	21,1
4	28	25,75
5	28,4	28
6	28,4	28

A double concave of flint glaſs	1ſt ſurface $= -0,5167 \times P.$ 2d ſurface $= -0,4843 \times P.$
A double convex of crown glaſs	1ſt ſurface $= 0,5219 \times P.$ 2d ſurface $= 0,4757 \times P.$

Semiaperture $= 0,1189 \times P.$

Second Formula.

A double convex of crown glaſs	1ſt ſurface $= 0,2829 \times P.$ 2d ſurface $= 2,0729 \times P.$
A double concave of flint glaſs	1ſt ſurface $= -2,1459 \times P.$ 2d ſurface $= -0,2955 \times P.$
A double convex of crown glaſs	1ſt ſurface $= 0,5938 \times P.$ 2d ſurface $= 2,5006 \times P.$

Semiaperture $= 0,0707 \times P.$

The principal focus of the firſt of thoſe achromatic lenſes was diſtant from its ſurface about 46 inches. That of the ſecond achromatic lens was diſtant about 46,3 inches.

Notwithſtanding the aberrations mentioned in the preceding pages, when glaſs lenſes are not very thick, they are reckoned to have a determined focus of refracted rays for ſuch rays as come from a ſingle radiant point, and the diſtance of that focus from the ſurface of the lens is called the *focal diſtance of thoſe rays*. Even a globe is ſaid to have ſuch a focus, meaning, however, of the middlemoſt part of the globe.

It is now neceſſary to deſcribe the method of determining that focal diſtance for the various ſorts of lenſes. This determination indeed may be obtained in all caſes from the general method deſcribed in page 190; but it will be uſeful to ſtate the principal reſults of ſuch inveſtigations for the more common lenſes, and likewiſe to give ſome more expeditious and pretty accurate rules for finding the foci of all ſorts of lenſes. We muſt however prefix a ſhort explanation of the action of flat plates.

In the firſt place, it muſt be recollected, that if a ray of light, however incident upon a refracting plate, like the glaſs plate AB, fig. 24, Plate XX. paſſes through it, the emergent part CD of that ray will always be parallel to the incident part EF, as long as the ſurfaces of the refracting plate are parallel

parallel to each other, and the plate is ſurrounded by the ſame uniform medium, be it air, or water, &c.; for though the ray is bent in going into the plate at the firſt ſurface, it is evident that it muſt be bent as much the contrary way in going out at the other ſurface of the plate.

If an object in a refracting medium be viewed by an eye ſituated in another medium of different refrangibility, the boundary of the two mediums being a plain ſurface, the viſual angle may be enlarged or diminiſhed, and of courſe the apparent ſize of the object may be enlarged or diminiſhed; viz. it will be enlarged if the eye be in the leſs refractive medium, and *vice verſa.*

Thus an object, A B, fig. 25, Plate XX. in water, will appear magnified to an eye at C, viz. ſituated in the air which is contiguous to the water; becauſe the external rays A F, B G, by falling obliquely upon the ſurface F G, are bent, and cauſed to ſubtend a larger angle at the eye. And the ſame thing muſt be underſtood of the intermediate rays, excepting D E, which, falling perpendicularly upon the ſurface, is not bent by it.

From what has been ſaid of a flat plate, it may be eaſily underſtood, that about the middle of the ſurface of every lens there is a point, upon which if a ray falls and paſſes through the lens, the emergent part will be parallel to the incident; for the point of incidence and the point of emergence may be ſituated ſo that if two planes touch the ſurfaces at thoſe points, they may be parallel to each other. That ray, or part of a pencil of light, which thus paſſes through the lens, without being bent, is called the *axis* of that pencil, and that axis always paſſes through the centre of the lens.

When rays of light fall upon the ſame lens with different inclinations, it is evident that after the refraction, they muſt have their foci at different diſtances from the lens; for inſtance, the ſame inward bending, or refraction, will incline towards each other, much ſooner thoſe rays which are already much inclined, than thoſe which are already leſs inclined or diverging.

When rays of light come parallel to each other, as thoſe which come from a point of the ſun's ſurface, or from any other diſtant point, and fall perpendicularly, or nearly ſo, upon the ſurface of a lens; then the focus of thoſe rays after refraction is called the *principal focus* of that lens, and its diſtance from the lens, the *principal focal diſtance* of that lens.

The principal focus of a lens may be found out either experimentally, which is by far the moſt expeditious method, or by computation.

In a plano-convex, double convex, or meniſcus, the principal focus is real; in the other lenſes the focus is virtual. In order to find out the principal focus of any of the former, place the lens before the ſun, ſo that its beams may fall perpendicularly upon it; then meaſure the diſtance at which the rays are collected in a white, round, and well defined ſpot, upon a piece of white paper, which for this purpoſe muſt be placed nearer or farther, &c. and that diſtance is the principal focal diſtance in queſtion. Inſtead of the ſun, ſome other diſtant luminous object will anſwer as well.

In order to find the virtual focus of any concave, plano-concave, or concavo-convex lens, cut a circular hole in a piece of black paper, and ſtick it on the lens, ſo that the centre of the hole may be in or very near the middle of the lens; alſo draw a circle on a piece of ſtiff paper or card, whoſe diameter is juſt double the diameter of the above-mentioned hole upon the lens; then hold the lens thus prepared perpendicular to the ſun beams, and move the card with the circle backwards and forwards on the other ſide of the lens, until the rays, which paſſing through the lens fall upon the card, may form a ſpot upon it exactly equal to the circle on the card; and the diſtance between the card and the lens is the principal virtual focal diſtance in queſtion; for if ſtraight lines be drawn from the edge of the ſpot on the card, and along the edge of the hole on the lens, they will meet at a point as diſtant from the other ſide of the lens as the card is from the firſt ſide.

The principal focal diſtance of a plano-convex glaſs lens is very nearly equal to the diameter of its curvature. But for a double and equally convex lens, that diſtance is nearly equal to the radius of curvature. In a plano-concave, the diſtance of the principal virtual focus from the lens is nearly equal to the diameter of the curvature. In a double and equally concave lens, that diſtance is equal to the radius of concavity *.

It

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* The following two rules are demonſtrated in Dr. Smith's Optics, B. II. Chap. III. Graveſande's Elements of Natural Philoſophy, B. V. Schol. to Chap. IX. and other works upon Optics.

I. *To find the focus of parallel rays falling perpendicularly, or nearly ſo, upon any given lens.*

Let E, fig. 1, 2, and 3, Plate XXI. be the centre of the lens, R and *r* the centres of its ſurfaces, (viz. of their ſphericities) R *r* its axis, *g* E G a line parallel to the incident ray upon the ſurface B, whoſe centre is R. Parallel to *g* E draw a ſemidiameter B R, in which produced, let V be the focus of the rays after their firſt refraction at the ſurface B; and joining V *r*, let it cut *g* E produced in G; and G will be the focus of the rays that emerge from the lens.

II. *The focus of incident rays upon a ſingle ſurface, ſphere or lens, being given, it is required to find the focus of the emergent rays.*

Let any point Q, fig. 4 and 5, Plate XXI. be the focus of incident rays upon a ſpherical ſurface, lens or ſphere, whoſe centre is E, and let other rays come parallel to the line Q E *q*, the contrary way to the given rays, and after refraction let them belong to the focus F (viz. mark the principal focus F); then taking E *f* equal to E F, ſay as Q F to F E, ſo E *f* to *f q*; and placing *f q* the contrary way from *f* to that of F Q from F, the point *q* will be the focus of the refracted rays, without

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It will be neceſſary to obſerve once for ever, that the directions of a given incident and refracted ray are the ſame when the latter is called the incident, and the former is called the refracted direction; for inſtance, if the incident rays are parallel, the refracted focus will be at a certain diſtance from the lens; now if a luminous object be ſituated at that diſtance, then the refracted rays will proceed parallel. The like thing muſt be underſtood of any two conjugate foci of a lens; for if either of them is called the radiant, the other will be the refracted focus.

When the incident rays, inſtead of being parallel, are either converging or diverging, then you may determine whether the focus is nearer or farther from the lens than the principal focus, by conſidering whether the lens be concave or convex, &c. which ſo far needs no particular explanation; but the preciſe diſtance of the focus in thoſe caſes may be eaſily determined from the ſecond rule in the note below.

We have hitherto taken notice of the progreſs of a ſingle pencil of rays (viz. ſuch as comes from a

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any ſenſible error; provided the point Q be not ſo remote from the axis, nor the ſurface ſo broad, as to cauſe any of the rays to fall too obliquely upon them.

When the rays do not come from a point, nor do they come parallel, but come convergingly, then their virtual focus muſt be conſidered as the radiant point.

ſingle point) through a lens; but the application of the ſame reaſoning to the various points of an object is ſo very eaſy, that a ſlight illuſtration is ſufficient to render it manifeſt.

Let DE, fig. 6, Plate XXI. be an object, AB a double convex lens, whoſe centre is C; and let us examine the pencils of rays which come from three points only of the object, ſince the ſituation of the intermediate pencils is evidently comprehended between thoſe three. Now of all the rays which proceed from each of thoſe points, that which paſſes through the centre C of the lens muſt (from what has been ſaid in page 227) proceed in a ſtraight direction*; ſo that DCI, FCH, and ECG, are ſtraight lines; ſecondly, the focus of the rays DBA, after refraction, muſt be ſomewhere in the axis or ſtraight line DCI; alſo that of the middle pencil, FBA muſt be ſomewhere in FCH, and the focus of the third pencil muſt be in ECG. Thirdly, the refracted focus of each pencil muſt be on the contrary ſide of the axis of the lens, to what its incident or radiant focus is; for inſtance, the refracted focus I is below the axis of the lens, whilſt its incident or radiant focus D is above it; and the refracted

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* The incident and refracted parts of that ray, properly ſpeaking, are not in one ſtraight line, but they are parallel to each other; yet when the lens is not remarkably thick, they may be ſafely conſidered as one ſtraight line, the difference being inſenſible.

focus G is above the axis, whilſt its radiant point E is below it: the conſequence of which is, that if the object D E be ſufficiently luminous, and a piece of white paper, or other flat and opaque body, be ſituated at G I, an image of the object D E will be formed upon it, but in an inverted poſition. If the opaque body be removed, then no image will be ſeen by a ſpectator ſituated on one ſide; for the rays of light, though they meet at their reſpective foci in I H G, yet they proceed divergingly beyond that place through the air or other tranſparent body, and none come to the lateral ſpectator. If the paper be ſituated nearer or farther from the lens than the place G I, then an imperfect image, or no image at all, will be formed upon it, becauſe the rays of the reſpective pencils do not meet at any other place.

From what has been ſaid above with reſpect to the conjugate foci of the ſame pencil, it will be clearly deduced, that if the object D E be brought nearer to the lens, the refracted foci, or the image G H I, will be formed farther from the lens, and *vice verſa*. And from this it follows, that (ſince the angles D C E, G C I, formed at the centre of the lens by the axes of the two extreme pencils, are equal *) when the diſtance of the object from the lens is equal to that of the image from the lens, then the ſize of the image is equal to that of the object;

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* Euclid's Elements, Book I. Prop. 15.

object; when the former diſtance is leſs than that of the latter, then the image is larger than the object; and when the former diſtance is longer than the latter, then the image is ſmaller than the object.

With reſpect to the brightneſs of that image it muſt be conſidered, that of the innumerable rays which are inceſſantly emitted in every direction from each point, for inſtance D, of the object, a conſiderable number, viz. D A B, falls upon the lens, and are converged to a ſingle point I; therefore that point muſt be more or leſs bright in proportion as the ſurface of the lens is larger or ſmaller. Hence alſo a very remarkable property of thoſe lenſes is eaſily comprehended, which is, that when an image GHI, is thus formed, if you cover part of the lens, be it the middlemoſt or ſome lateral part of it, the image IG will not thereby be rendered partly inviſible—the whole image will be ſeen as well as before, but it will appear leſs bright than before; for if we conſider each indefinite part of the lens, we may eaſily perceive that rays of light from every point of the object muſt paſs through that part, and muſt meet at their reſpective foci in G H I.

The above explanation of the progreſs of various pencils through a convex lens, may, *mutatis mutandis*, without much difficulty be adapted to explain the action of concave lenſes.

Upon the whole, it muſt be recollected, that by the action of a double convex lens, or plano-convex

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and meniſcus, the rays of light which paſs through them are made to incline more towards each other, or to proceed leſs divergingly than they did before, excepting after their meeting or foci; for beyond that place they proceed divergingly. On the contrary, by the action of double concave plano-concave, and concavo-convex lenſes, the rays of light which paſs through them are made to diverge more, or to proceed leſs inclined towards each other, than they did before their entrance into the lens.

We ſhall now deſcribe a few eaſy experiments, which prove in a familiar manner moſt of the above-mentioned properties of lenſes.

Take an hollow globe of glaſs, or globular decanter; make an hole of about a quarter of the globe's diameter in a piece of brown paper, and ſtick the paper on one ſide of the globe or decanter; fill the veſſel with water, then preſent it with the covered ſide to the ſun, and the rays which paſs through the hole in the paper and through the water, will be collected to a focus or round and well defined ſpot, on the other ſide of the globe, which may be received upon a piece of paper; and its diſtance from the globe being meaſured, will be found equal to half the diameter of the globe. If the experiment be repeated with the empty globe, no focus will be formed (ſee page 226). If, inſtead of water, the globe be filled with ſpirit of turpentine, the focal diſtance will be found ſhorter than when water is uſed, the refractive property of that ſpirit being greater

greater than that of water. If the experiment be tried with a ſolid globe of glaſs, the diſtance of the focus from the neareſt part of its ſurface will be equal to one quarter of the globe's diameter.

The reaſon why one ſide of the globe muſt be covered with a perforated paper, is, that when all the globe is expoſed to the light, the rays which fall upon the more external places will have their refracted foci nearer to the globe than thoſe which fall nearer to the axis, all which foci form the cauſtics by refraction (ſee page 220) which curves may be obſerved in the following manner:

When the light of the ſun, or of a candle, &c. is refracted through a globe, be it of ſolid glaſs or a globular decanter filled with water, ſpirit of turpentine, &c. and falls upon a table cloth, or upon a piece of white paper held parallel and very near to the axis of the light, the luminous figure thereby formed, is bounded by two bright curves, which are the above-mentioned cauſtics; which, as they recede from the globe, approach each other and the axis of the pencil, until they touch it, and there form a ſharp angle, whoſe vertex is the principal focus of the pencil.

Having covered either ſide of a convex lens with paper, in which there are ſeveral ſmall holes made with a pin, and having expoſed the lens directly to the ſun, the rays which paſs through the holes will appear like ſo many white ſpots upon a paper held pretty cloſe behind the glaſs; and theſe ſpots will come cloſer together as the paper is gradually drawn back

back from the lens, until at laſt they all unite in one ſpot, which is the focus. This ſhews the reaſon why that ſpot is ſo very bright, and why it burns with ſo much power as experience ſhews it to do. By inclining the lens a little, that focal ſpot will not be ſenſibly altered. If the paper be removed ſtill farther from the lens, the ſpots will ſeparate again, nor will they ever meet again; for beyond the focus the rays proceed divergingly.

If the above-mentioned experiment be tried with a concave lens, the ſpots will never meet, but they will be found to recede continually from each other, in proportion as the white paper is removed from the lens.

" Having found the focal diſtance, E F, fig. 7, Plate XXI. of a convex glaſs lens, fix it flat againſt a moderate hole made in a thin board C E, and place it upright upon a long table or floor. Through the point C, directly under the middle of the glaſs, draw a long line AB, perpendicular to the board, in which meaſure the principal focal diſtance of the lens from C to F, and from F to I, I to II, II to III, &c. and alſo on the other ſide, from C to *f*, and from *f* to 1, 1 to 2, 2 to 3, &c. then taking ½, ⅓, ¼, &c. of that focal diſtance, ſet them off from F towards I, and alſo from *f* towards 1, and put the figures ½, ⅓, ¼, to the points of diviſion, as in the figure; laſtly, having darkened the room, if a candle be placed at Q over the mark I, the rays which paſs through the glaſs will be united at *q* upon a paper held over the oppoſite mark 1; and removing

moving the candle to II and the paper to $\frac{1}{2}$, the rays will be united here alſo; and likewiſe when the candle and paper are removed to III and $\frac{1}{3}$, IV and $\frac{1}{4}$, &c. and the effect will be the ſame if the paper and candle be tranſpoſed into each other's places. It appears that fq decreaſes in the ſame proportion as FQ increaſes, and the contrary.

"Things remaining as they were, when a ſecond candle is placed on either ſide of the firſt at the ſame diſtance from the glaſs, the union of its rays will make another image upon the paper q on the contrary ſide of the axis QEq; and the diſtance between the two images will be found to bear the ſame proportion to the diſtance between the candles, as the diſtance of the images from the glaſs bears to the diſtance of the candles from the glaſs. Theſe obſervations confirm the reaſon why the image of a ſingle candle is inverted upon the paper; and why its magnitude is altered when its place is altered. Becauſe what has been obſerved of two candles is applicable to any two points of the ſame candle *."

If in either of the above-mentioned experiments part of the lens be covered with ſome opaque body, ſuch as a brown piece of paper, the whole image of the ſingle candle, or of the two candles, will be ſeen exactly as when the whole lens is uncovered, excepting that it will appear leſs bright in proportion to the covered ſurface of the lens.

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* Dr. Smith's Optics, Book I. Chap. II.

CHAPTER VI.

DESCRIPTION OF THE EYE, AND OF VISION.

OUR perception of objects produced by the action of light, is called *viſion*. The organ which receives the impreſſion of that action, and through which the perception is communicated to the ſenſorium, is the *eye*, of which the human being has two, and of which no animal, that we know of, has leſs than two.

Of the five external ſenſes of our body, the conſtruction of the eye ſeems to be beſt underſtood; yet this goes no farther than to ſhew that a picture or image of the objects we perceive, is painted within the eye, whilſt the objects are before us, and that the eye is conſtructed ſo as to adapt itſelf to the formation of that image in different circumſtances; but we do not pretend to explain the manner in which the perception of that image is communicated to the ſenſorium through the nerve, upon a projection of which that image is formed. It is neceſſary, for the purpoſe of explaining how that image is formed, &c. to deſcribe the wonderful conſtruction and action of the eye; but

but in order to render its action as well as the deſcription of its parts more intelligible to the novice, we ſhall prefix a ſhort deſcription of the principle of what is called a *camera obſcura*, or dark chamber.

If a ſmall hole be made in the ſide of a darkened room or box, and bright objects, ſuch as trees, animals, &c. illuminated by the direct rays of the ſun, happen to be out of the room, and on that ſide of the room where the hole is, then an inverted image of thoſe objects will be ſeen either upon the oppoſite wall, or upon a ſcreen, within the room; but that image is imperfect and indiſtinct. When the hole is very ſmall, as about a tenth of an inch in diameter, few rays can paſs through it, and of courſe the image is faint. When the hole is conſiderably larger, the various rays which belong to each luminous or radiant point come divergingly through the hole, are ſcattered upon the wall or ſcreen, and great indiſtinction enſues. In either caſe, the rays are more or leſs inflected by the ſides of the aperture.

If a convex lens be applied to the hole, then a beautiful image of the external objects in their true colours, but inverted, will be painted upon the ſcreen within the room; but the ſcreen muſt be placed at the focal diſtance of the lens, and that focal diſtance changes according as the diſtance of the external objects from the room is altered *: hence not all

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* See what has been ſaid concerning the conjugate foci of lenſes in page 218.

the external objects can be well defined and properly depicted upon the ſcreen; for as they are at unequal diſtances, the focal diſtances within the room muſt likewiſe be unequal, and of courſe the ſcreen may be ſituated properly for ſome of them, but not for them all; yet when the external objects are not very near, the ſame ſituation of the ſcreen will do for them all ſufficiently to render them diſcernible, and to form a pleaſant picture of the whole.

In the latter caſe, when a convex lens is ſituated at the hole of the dark chamber, various advantages are obtained by it. In the firſt place, the pencils of light being refracted by the lens, are cauſed to converge to their reſpective foci; hence the hole and the lens may be large, in conſequence of which a great quantity of light from every ſingle point of the objects is admitted; and ſecondly, the inflection of light is avoided by the enlargement of the hole.

It will appear from the following deſcription, that the eye is a moſt excellent camera obſcura, having all the neceſſary properties of it to a moſt accurate degree of nicety. It is a dark room, with one aperture for the admiſſion of light, with lenſes fit to form a picture of external objects on the hind part of its cavity, and is capable of all the neceſſary adjuſtments within certain limits.

Fig. 8, Plate XXI. exhibits the ſection of a human eye, larger than its real or moſt uſual ſize. Its figure is nearly globular. What is ſeen of the eye

eye in a living ſubject, is part of a convex white protuberance, with a circular tranſparent ſpot in the middle, which reſts upon a radiated baſis, differently coloured in different perſons, &c. This viſible part of the eye is repreſented by the front view, fig. 9, and by the portion ABECD, in the ſection fig. 8, BEC is the tranſparent part thereof. The hind part AFD is ſurrounded by ſix muſcles, the extremities of which are firmly faſtened to the external coat of the eye, and are deſtined to move it in the different neceſſary directions. The particular deſcription of thoſe muſcles does not belong to this work.

The bulb of the eye conſiſts of the external coats or tunics ABECDFA, and of internal humours that fill the whole cavity, and keep the tunics inflated in a form nearly globular.

The membranes, coats, or integuments of the eye are as follows: the external firm one is called the *ſclerotica*, the anterior portion of which, viz. BEC, is tranſparent and more convex, and is called the *cornea*, (or tranſparent horny ſubſtance.) The portion adjacent to the cornea, viz. *AB*, *DC*, is white; hence it is commonly called the white of the eye. The next membrane within the ſclerotica, is called the *choroides*. This is extended at *a b* under the cornea, and forms the coloured part of the eye, *ae*, *bc*, called the *iris*, (ſee alſo fig. 9, which repreſents a front view of the eye.) This iris is formed of muſcular fibres, diſpoſed in two directions, viz. ſome are like radii, tending towards the centre, and others are circular. The iris is perforated near its middle, and that perforation is called the *pupil.* This pupil is not always of the ſame ſize; for by the contraction or relaxation of the fibres of the iris, the pupil becomes larger or ſmaller, viz. when the radial fibres contract and the circular are relaxed, the pupil becomes enlarged; but when the latter are contracted and the former relaxed, then the pupil becomes diminiſhed*. The colour of the iris is different in different perſons; but it does not ſeem that its colour is connected with any peculiarity of conſtitution, or of configuration of the human body.

Under the iris there is a prolongation *df* of the choroides, which forms a circular fibrous band, to which the cryſtalline humour *d o f* is attached. This circular band is called the *ligamentum ciliare.*

At the hind part F of the eye, but not exactly oppoſite to the pupil, a prolongation of the coats of the eye is to be obſerved. This prolongation envelopes

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* This is an admirable ſtructure, which, whether in an enlarged or contracted ſtate, does always preſerve the circular figure of the pupil.

The pupil is ſeldom quite concentric with the iris. Its aperture varies conſiderably, and differently with different individuals. In ſome perſons its diameter, in its contracted ſtate, is about one-tenth of an inch, and in the moſt enlarged ſtate it exceeds a quarter of an inch; in others it varies leſs.

a nerve that comes from the brain, and is called the *optic nerve*, the inner or medullar part of which ſpreads itſelf over the choroides, as far as the ciliary proceſs *df*, and forms the innermoſt coat of the eye, called the *retina*. This is a thin and whitiſh membrane, looking like the fineſt ſort of net-work, or of linen *.

The above-mentioned membranes contain three tranſparent humours, which are called the *aqueous*, the *cryſtalline*, and the *vitreous*.

The *cryſtalline* humour *dosf* is a conſiſtent cellular tranſparent ſubſtance in the ſhape of a double convex lens, whoſe hind ſurface *dof* is more convex than the other ſurface *dsf* †. The edge of this lens is attached

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* The inſertion of the optic nerve is not exactly in the *axis* of the eye (viz. in the ſtraight line E I, which is ſuppoſed to paſs through the eye in a direction perpendicular to the cornea, and to the cryſtalline lens;) but in each eye it deviates from the axis towards the noſe, by about the 14th part of the whole circumference of the eye: but this diſtance is not the ſame in all eyes.

For a more particular account of the membranes of the eye, as alſo of the veſſels, glands, &c. that belong to the ſame organ (which would be unneceſſary for our preſent purpoſe,) ſee the anatomical writers.

† It is pretty much the opinion of anatomiſts, that the cryſtalline lens conſiſts of muſcular fibres. Its ſpecific gravity is about 1,1, viz. very little above that of water. Its conſiſtence, and of courſe its refractive power, is not uniform

attached all round to the ligamentum ciliare. All the cavity between the cornea and the cryſtalline humour, is filled with a fluid called the *aqueous* fluid [*]. The remaining, which forms the greateſt, part of the cavity of the eye, viz. *o f m l k d o*, is filled with another fluid called the *vitreous* [†].

The figures 8 and 9, repreſent the eye, for the ſake of perſpicuity, larger than its natural ſize, and not in exact proportion; but the proper dimenſions, as deduced from a great number of actual meaſurements, will be found in the note [‡].

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form throughout. "On the whole, *Dr. Thomas Young* "*ſays*, it is probable that the refractive power of the centre "of the human cryſtalline, in its living ſtate, is to that of "water nearly as 18 to 17; that the water imbibed after "death reduces it to the ratio of 21 to 20; but that, on "account of the unequable denſity of the lens, its effect "in the eye is equivalent to a refraction of 14 to 13 for its "whole ſize." Phil. Tranſ. vol. for 1801, p. 42.

[*] This is a very limpid water, and like water in reſpect to conſiſtency, ſpecific gravity, and refractive power.

[†] This, which is by far the moſt abundant humour of the eye, conſiſts of ſmall cells diſtended with a limpid watery fluid. It but a little exceeds water in reſpect to ſpecific gravity and refractive power.

[‡] *Dimenſions of the human eye at a medium, in decimal parts of an inch.*

The diameter of the eye from outſide to outſide, taken at a mean from the eyes of ſix adult perſons - - - - - - - - 0,940

Diſtance

When the eye is open, and illuminated objects are before it, inverted pictures of thoſe objects are formed upon the retina, by the refractive powers of the above-mentioned three humours. If the thicker coats on the back of a freſh eye be removed, and the eye thus prepared be turned towards objects that are well illuminated, their pictures may be clearly perceived through the remaining thin coat.

Whoever will trace the progreſs of parallel rays (viz. ſuch as come from a very diſtant luminous point) which may be eaſily done from the meaſure-

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Diſtance of the external ſurface of the cornea from the neareſt ſurface of the cryſtalline lens - -	0,104
Radius of convexity of the cornea - - -	0,333
Radius of convexity of the anterior ſurface of the cryſtalline lens, at a mean from 26 eyes - -	0,331
Radius of convexity of the hinder ſurface of the cryſtalline, from the ſame eyes - - -	0,250
Thickneſs of the cryſtalline at a mean, from the ſame eyes - - - - - - -	0,185
Thickneſs of the ſclerotica, about - - -	0,025
Thickneſs of the choroides and retina together, about	0,015

The ſine of the angle of incidence to the ſine of refraction at E, viz. from the air into the cornea and aqueous humour, is (as from air into water) or as 4 to 3 nearly. At *s*, viz. from the aqueous into the cryſtalline, the ratio of refraction is nearly as 13 to 12. At *o*, viz. from the cryſtalline into the vitreous humour, the ratio of refraction is nearly as 12 to 13.

ments that are mentioned in the note, and from what has been ſaid in page 190, will find, that by the refractions of all the humours through which they muſt paſs, they will be collected to a focus on the retina, which therefore is the true place of the image. But at the ſame time it is evident that if that be the focal diſtance for parallel rays, it cannot be the focal diſtance for diverging rays; or, in other words, when the objects are ſituated at a few feet diſtance from the eye, their true images muſt be formed farther back; conſequently their images upon the retina muſt be imperfect, unleſs the retina be ſituated farther back by an elongation of the axis of the eye, or the focal diſtance be ſhortened by the alteration of ſome other part. But ſince we may perceive either diſtant or near objects diſtinctly, it is evident that ſome ſuch alteration does actually and neceſſarily take place. This is called the adjuſtment or accommodation of the eye for diſtinct viſion; but the difficulty is to determine how this adjuſtment is effected.

By ſome perſons it has been attributed to a change in the length of the eye, and by others to a change of curvature in the cornea; but ſome very recent experiments render thoſe alterations unlikely, at leaſt to the full amount of what may be required. Other ingenious perſons have attributed the alteration to a change either of the ſhape of the cryſtalline lens, or of its ſituation, or of both; and this opinion ſeems upon the whole to be nearer to the truth *.

That the eye cannot ſee both near and remote objects diſtinctly at the ſame time, may be eaſily proved. Let a tree, a houſe, or ſome other object be upwards of 50 feet from you; ſhut one eye, and whilſt you are looking with a ſingle eye at the tree, &c. hold a pin, a pencil, or ſome other object in the ſame direction at about a foot diſtance from the eye; and it will be found that whilſt you ſee the pin diſtinctly, the tree will appear indiſtinct; but if you adjuſt your eye ſo as to ſee the tree diſtinctly, then the pin will appear indiſtinct.

The eyes of ſome perſons are more capable of adjuſtment than thoſe of others. In old perſons the humours grow thicker, and the parts leſs pliable; hence their eyes are leſs capable of adjuſtment than in young perſons.

The eyes of ſome perſons can be adjuſted for diſtant objects better than for near objects, and *vice verſa.* When the eye is defective, and by its ſize or other conformation, parallel rays form their foci before they arrive at the retina, then the perſon can ſee very near objects only. Such perſons are ſaid

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* For farther information on this ſubject, the reader may peruſe Prieſtley's Hiſtory of Viſion, Light, and Colours; Olbers's *de oculi mutationibus internis*; and Young's Paper in the Philoſophical Tranſactions, vol. for 1801. Art. II.

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to be near-ſighted, or they are called *myopes*. When the eye is flatter than ordinary, then the foci of rays from pretty near objects are formed beyond the retina. Perſons with ſuch eyes are called *preſbytæ*; — they can adjuſt their eyes for objects beyond a certain diſtance only. The latter is generally the caſe with old perſons; but the eyes of old perſons ſometimes are incapable of adjuſtment both for very near and for very diſtant objects. This comes from a rigidity or want of pliability in the parts *.

Thoſe imperfections may in great meaſure be remedied by the uſe of proper glaſſes or ſpectacles; for ſince in near-ſighted perſons the rays of light converge to a focus too ſoon, viz. before they come to the retina, concave lenſes, which diminiſh the convergency, muſt remove the imperfection. And for thoſe who can ſee diſtant objects only with tolerable diſtinction, viz. in whoſe eyes the rays do not converge ſoon enough, convex lenſes, which increaſe the convergency, muſt remove the imperfection.

When the defect comes from rigidity, as in ſome old perſons, then thoſe perſons require concave glaſſes for viewing diſtant objects, and convex glaſſes

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* Thoſe defects are frequently brought on or increaſed by habit, as by the conſtant cuſtom of viewing objects either from too near or from too great a diſtance; as alſo by the uſe of improper glaſſes.

for viewing near objects; for their eyes want both adjuſtments *.

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* The eſſential and extenſive uſe of ſpectacles, which affords comfort to ſo great a number of individuals, who would otherwiſe be a burden to themſelves and to ſociety, is an inſtance of the great uſefulneſs of the ſcience of optics.

No pains have been ſpared to render ſpectacles as perfect as poſſible, and a variety of contrivances have been from time to time offered to the public. Spectacles have been made with two lenſes for each eye; alſo the lenſes have been made plano-convex or plano-concave, or of other ſhapes; but upon the whole, ſingle lenſes, either double concave, or double convex, of clear glaſs, well poliſhed and regularly formed, are the beſt.

When the eyes of perſons firſt begin to be affected by age, the opticians furniſh them with ſpectacle lenſes, of about 40 inches focus, which glaſſes are therefore called number 1ſt, or glaſſes of the firſt ſight; viz. for the ſight when it firſt begins to be impaired by age. But I find conſiderable difference between the focal diſtances of ſpectacles, N° 1. made by different opticians. When the focal length is about 16 inches, the lenſes are called N° 2. About twelve inches is the focal length of N° 3. Ten inches is what they call N° 4. Nine inches is that of N° 5. Eight inches is the focal length of N° 6. Seven inches is the focal length of number 7. Six inches is the focal length of N° 8.; and ſometimes they make ſpectacles of a focus ſhorter ſtill. Concave ſpectacles are alſo named by ſimilar numbers.

In chooſing ſpectacles, actual trial is the beſt guide; but care muſt be had to uſe ſpectacles that do not magnify more

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The capability of adjuſtment is greater or leſs in different eyes, and it is frequently different in the two eyes of the very ſame perſon; but in all eyes there is a limit, within which viſion is not diſtinct. This is called the *limit of diſtinct viſion*; and with ſome perſons it is as ſhort as one inch, whilſt in others it exceeds 20 inches; but in common it will be found to lie between ſix and 10 inches.

All the retina, as far as it is extended, is capable of receiving the moſt perfect image of objects. There is, however, a ſingle ſpot where no viſion takes place; and this ſpot, which is about a 40th of an inch in diameter, lies exactly upon the inſertion of the optic nerve; ſo that we cannot perceive the image of any object that falls upon this ſpot at the hind part of the eye, provided the other eye be ſhut. The exiſtence of this (which we may call

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than is juſt ſufficient either for reading, or for other neceſſary purpoſes.

When a variety of ſpectacles cannot actually be tried, the defect of the ſight may be expreſſed by mentioning the diſtance from which the perſon can read, or other peculiarities, from which the neceſſary glaſſes may be determined pretty nearly. An inſtrument for meaſuring the exact limits of diſtinct viſion was ſome years ago contrived by Dr. Porterfield, who named it an *Optometer* (ſee his Work on the Eye, vol. I.) and an improved one for the ſame purpoſe was lately contrived by Dr. Thomas Young. See his Paper on the Mechaniſm of the Eye, in the Philoſophical Tranſactions, vol. for 1801.

inſenſible) ſpot is moſt convincingly proved by the following eaſy experiment.

Let three pieces of paper of different ſhapes, A, B, C, fig. 10, Plate XXI. be faſtened on a wall, at the diſtance of about two feet from one another, and let a perſon, keeping one of his eyes ſhut, place himſelf nearly oppoſite to the middle paper B, and beginning pretty near to it, let him retire gradually backwards, whilſt the open eye is turned obliquely towards the outſide paper, viz. that paper which is next to the eye that is ſhut; he will find a ſituation (which generally is at the diſtance of about 10 feet from the papers) where the middle paper will entirely diſappear, while the outermoſt papers continue viſible. In that ſituation the image of the middle paper falls exactly upon the inſertion of the optic nerve.

This obſervation has been often adduced as the foundation of an argument to prove, that the ſeat of viſion is not exactly at the retina, and that either the choroides or ſome other part of the eye receives the impreſſion of light, &c.: but as nothing poſitive is known with reſpect to this ſubject, viz. of the manner in which the perception of objects is conveyed to the ſenſorium; and having ſhewn that a picture of the objects, &c. is actually painted on the retina, which is going as far as we can in tracing the action of light; I ſhall not detain my reader with long and unprofitable diſquiſitions relative to it.

There is another remarkable adjuſtment of the eye that requires to be explained; and this is the contraction and enlargement of the pupil.

It has been ſhewn above, that of the innumerable rays which proceed from every ſingle point of an object, *cæteris paribus*, a greater or leſs quantity falls upon a lens in proportion as the lens is larger or ſmaller, and in the ſame proportion is the refracted focus or image, more or leſs bright. Now, by inſpecting fig. 11, Plate XXI. it will appear, that after the ſame manner more or leſs rays from every ſingle point of the object A C B, will enter the eye in proportion as the pupil is open more or leſs, and the correſponding points *a*, *b*, *c*, of the image will be proportionately more or leſs bright. But as the light from certain objects, ſuch as the ſun, a bright fire, &c. would be hurtful to the eye, and in other caſes the inſufficient quantity of light would render the perception of objects too faint; therefore provident nature has furniſhed the eye with a method of enlarging or contracting its aperture, which is effected by the action of the iris, which, as has been ſhewn above, is a prolongation of the choroides; and ſo eaſy and involuntary is the contraction of that membrane, that without the leaſt conſideration we readily adapt it to receive a proper quantity of light in moſt caſes. Let a perſon turn his eyes towards a pretty dark place, and in that ſituation by looking at his eyes, you will find the pupils much dilated; then place a lighted candle before

before his eyes at about three or four inches diſtance, and you will perceive the pupils to become remarkably narrow.

In ſome perſons the pupil is in all caſes larger than in others, nor can they contract it ſufficiently. Such perſons ſee beſt with little light. Other perſons have their pupils naturally narrower than ordinary, and of courſe thoſe perſons ſee beſt in a bright light. Sometimes the pupil loſes its contraction entirely.

Though a more open pupil will admit more light than one which is leſs open, and of courſe objects that are leſs luminous may be perceived by the former eye than by the latter; yet the total want of light renders objects inviſible to any eye. Fair and ſatisfactory experiments prove that, in a room perfectly dark, no object can be perceived even by the eyes of a cat.

Having deſcribed the ſtructure of the human eye, and the progreſs of light through it; our next object is to explain ſeveral phenomena of viſion, which otherwiſe might be conſidered irreconcileable to the common theory of light; and in the firſt place, it may be naturally inquired how is it that we perceive objects ſingle, if they are ſingle, or of their real number, though we look at them with two eyes, and though a picture of each object is formed in each eye.

Of the various opinions, which have been advanced in explanation of this difficulty, the moſt ſatisfactory

tisfactory is, that in the two eyes there are correſponding parts of the retinas which are probably ſuſceptible of the ſame impreſſion in equal degree, and convey it to the ſenſorium in that equal degree: hence as long as ſimilar points of the images fall upon the correſponding points of the retinas, the perception of the ſame object is ſingle, otherwiſe it is double.

Fig. 12, Plate XXI. exhibits two eyes directed to the ſame object A B; and it is likely that at oppoſite diſtances from the inſertions of the optic nerves the retinas have correſponding tenſions, irritabilities, or ſuſceptibilities; for inſtance, *a* may correſpond to *a*, *b* to *b*; and as long as the like parts of the images fall upon thoſe correſponding parts, the object appears ſingle. It is evident that for this purpoſe the axes of the eyes, that is the eyes themſelves, muſt be turned more or leſs towards each other, according as the object to which they are directed is nearer or farther, and this is actually the caſe; ſo that according to the diſtance of the object, we not only adjuſt each eye for diſtinct viſion at that diſtance, but alſo adjuſt the direction of both eyes in order to produce ſingle viſion of ſingle objects. In confirmation of this theory, hold up a finger before your eyes at the diſtance of 8 or 10 inches, whilſt a man, a window, or other object, is before you at a much greater diſtance, and you will find that if you endeavour to look ſteadily at the finger, viz. by directing the axis of both eyes towards it, the man,

&c. will appear not only indiſtinct, but alſo double. If you endeavour to ſee the man diſtinctly and ſingle, the finger will at the ſame time appear double and indiſtinct.

It is from this adjuſtment that we are in great meaſure enabled to judge of the diſtances of objects, when thoſe diſtances are not very great. It is from this adjuſtment, or from the direction of the two eyes, that we judge whether a perſon is looking at us or not.

When from particular configuration, or from bad habit, the axes of the two eyes do not appear to be directed to the object which they actually have in view, then the perſon is ſaid to *ſquint*. But it does not follow that the ſquinting perſon ſees every object double; for the apparent improper direction of the eyes may be owing to the unuſual ſituation of the parts of the eye; yet the like parts of the two images may fall upon correſponding parts of the retinas.

In the next place it may be inquired how do we perceive objects erect or in their proper ſituations, conſidering that the image is inverted upon the retina. Various opinions have been advanced in explanation of this difficulty; but the moſt plauſible is, that the mind contemplates the object and not its image, and that by experience we are accuſtomed to conſider the lower part of the picture as indicating the upper part of the object, and *vice verſa*. Or by referring the ſituation of objects to other ſurrounding objects: hence if a perſon looks at a houſe, and

and whether he turns his head one way or the other, and even upſide down, the houſe does always appear erect.

The perceptions of our ſenſes are ſo difficultly inveſtigated, and ſo influenced by aſſuefaction, &c. that we can hardly comprehend any of them with full certainty and ſatisfaction.

Our judgment of the diſtances as alſo of the ſize of objects which we perceive by our ſight, is influenced by the concurrence of ſeveral circumſtances; viz. we are directed to form our judgment, 1ſt, from the apparent magnitude of the objects; 2dly, from the ſtrength of the colouring and diſtinctneſs of their minute parts; 3dly, from the direction of the two eyes; and 4thly, from their ſituation in relation to other objects. And our judgment is more or leſs liable to be wrong, according as one or more of thoſe circumſtances are wanting. Thus a perſon with one eye is leſs capable to judge of the diſtance of an object than a man with two eyes, as in that caſe the third circumſtance is wanting. Thus if a man ſix feet high be ſituated at 40 feet diſtance from us, and a boy 3 feet high be ſituated at 20 feet diſtance, they will ſubtend equal angles at our eyes, and therefore they ought to appear equally high; yet from the formation of their limbs, and their ſituation relatively to other objects, we do by no means think them equally high.

A ſmall object near us, and a large one at a proportionate diſtance, ſubtend the ſame viſual angle;

but the diſtant object appears indiſtinct. Hence if a ſmall and near object is by any means rendered indiſtinct, we are apt to take it for a large diſtant object. Thus a fly or other inſect often paſſes by our eyes, when the eyes are directed to ſome other object; in which caſe the fly appears indiſtinct, and we frequently take it for a crow at a diſtance.

When the moon is near the horizon, the thickneſs of the atmoſphere renders it leſs bright and leſs diſtinct than when it is higher up: hence we imagine it to be farther off in the former caſe than in the latter; and becauſe we imagine it to be farther off, we take it to be a much larger object than when it is higher up; in which ſituation we imagine it to be nearer to us, from its appearing much brighter. For it appears from actual meaſurement, that the ſize of the moon is ſmaller near the horizon than when it ſtands higher up. So that this well known phenomenon of the *horizontal moon* is merely an illuſion.

The very remarkable exhibition made in London for ſome years paſt, under the name of *Panorama*, produces a ſurprizing effect from the ſame abovementioned cauſes. A circular picture, in a circular building whoſe diameter is about 40 feet, is exhibited to the ſpectator, who ſtands near the centre of the circle, and every other object with which the painted objects might be compared, are removed from his ſight; in conſequence of which, and on account of the indiſtinctneſs of the painted objects, he is led to imagine that they are real objects of the natural ſize at much greater diſtances.

With reſpect to apparent motion, our judgment is likewiſe apt to be miſtaken; for when our eyes are directed to any particular object, and follow it inſenſibly, every other object which deviates from that direction, is frequently taken for a moving object. Thus when the clouds are paſſing ſwiftly by the moon, if we look ſteadily at the clouds, the moon appears to run ſwiftly by. If we look ſteadily at the moon, then the clouds appear to move on rapidly. Thus alſo a perſon in a boat, keeping his eyes either immoveable, or looking at ſome part of the boat, will frequently imagine that the coaſt is moving away.

A queſtion is frequently aſked with reſpect to our perception of black objects, viz. that ſince blackneſs is a privation or abſorption of all colours, what do we ſee when we perceive a black object? The anſwer to this queſtion is, that we ſee not the black object itſelf, but we ſee the objects that ſurround it, the boundaries of which on that ſide are the ſame as the boundaries of the black object. A deep hole from which no light is reflected, and a black ſpot of the ſame ſize appear alike to our eyes. When we look at a black hat, or other like object, we perceive the bendings, edges, and other prominent parts of it, becauſe thoſe parts are not perfectly dark; but they reflect ſome light to our eyes, ſufficient to diſtinguiſh one part from another.

The above-mentioned deceptions, to which our eyes are liable, inſtruct us not to believe the ſuppoſed infallible evidence of the ſight, when reaſon is againſt it.

There is one phenomenon more of ſimple ſight, which deſerves to be explained before we paſs on to the examination of viſion through lenſes.

When the eye-lids are pretty cloſe, or almoſt ſhut, and eſpecially when they are moiſt, on looking at a candle, two long irradiations NM are ſeen to dart from the candle upwards and downwards, as in fig. 13, Plate XXI. the cauſe of which is, that the rays of light which fall upon the edge of the lower eye-lid, as at I, are by it reflected into the eye at L D, where it forms a long ſpectrum, on account of the curvature of the edge of the eye-lid; and for the ſame reaſon the rays which fall upon the edge of the upper eye-lid at H, are reflected by it, and form the long ſpectrum O X, on the oppoſite ſide of the eye. In fact, if by the interpoſition of an opaque body P, the upper rays be intercepted, then the lower ſpectrum or irradiation will vaniſh; and, if the lower rays be intercepted, then the upper irradiation will vaniſh.

The eyes of different perſons, in all probability, do not receive the ſame impreſſions from the ſame colours; and this is ſometimes the caſe with the ſame perſon at different times, eſpecially when the body is not in a ſound ſtate. To ſuch perſons all objects ſometimes appear tinged either yellow, or green, or red, &c. Several caſes are recorded, in the Philoſophical and other Tranſactions of learned ſocieties, of perſons who laboured under thoſe imperfections of ſight, as alſo of ſome who could not diſtinguiſh certain colours from one another. Thoſe imperfections may ariſe from a mixture of particular juices with the humours of the eye, or from particular configurations, with which however we are not acquainted.

With reſpect to the phenomena of viſion through glaſs lenſes, perhaps what has been ſaid in the preceding pages might be deemed ſufficient, viz. that convex lenſes, by inclining the rays more towards each other, before they come to a focus, increaſe the viſual angle, and enlarge or magnify the appearance of the object; and that, on the contrary, the concave lenſes diminiſh the viſual angle, &c. But notwithſtanding the univerſality of this principle, moſt beginners find it difficult to comprehend the real action of convex lenſes, and to account for all their effects. It will therefore be neceſſary to give a more particular explanation of the effects of the laſt mentioned lenſes, eſpecially as the ſame is of conſiderable aſſiſtance in explaining the properties of moſt of the optical inſtruments, which will be deſcribed in the next chapter.

When an object, ſituated in the focus of a convex lens, is viewed by an eye ſituated on the other ſide of the lens, that object will always appear larger than it would if the lens were not interpoſed:

poſed: but if, when the lens is removed, the object be brought nearer to the eye, then it will appear as large as it did in its former ſituation, viz. when it was viewed through the lens; for by bringing the object nearer to the naked eye, the viſual angle is enlarged, as it was enlarged in the former caſe by the refraction of the lens that was interpoſed.

Could we bring objects unlimitedly near to our eyes, and could we adjuſt our eyes for viewing thoſe objects diſtinctly at any diſtance, then convex lenſes would be uſeleſs. But our eyes are capable of adjuſtment within certain limits, viz. for rays that come from any ſingle radiant point, either parallel or nearly ſo. When the object is nearer than ſix, or eight, or ten inches, the rays are too divergent for the eyes of moſt perſons. This diſtance therefore, viz. eight inches, may be reckoned as the ordinary limit of diſtinct viſion.

It has been alſo obſerved, that few men can diſtinguiſh an object which ſubtends at the eye an angle ſmaller than half a minute: therefore an object, whoſe diameter is ſmaller than the chord of half a minute to a radius of eight inches, is the leaſt object which the naked eyes of moſt men can diſtinguiſh. The diameter of ſuch an object is 0,00116 of an inch *.

Now the great uſe of lenſes is, to enable us to diſtinguiſh objects that are otherwiſe inviſible to

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* From the Trigonometrical Tables.

us, viz. when the whole object, or any part of it that may be deſired to be diſtinguiſhed, ſubtends an angle ſmaller than half a minute, or is ſmaller than 0,00116 of an inch. The lens, or the combination of lenſes, that perform this office are called *microſcopes*; and in the former caſe it is called a *ſingle microſcope*, whereas in the latter it is called a *compound microſcope*.

A ſingle lens (as has been already obſerved in the preceding pages) when an object is placed before it, converges the rays of each radiant point to a focus on the other ſide, where, if a ſcreen be ſituated, an image of that object will be formed; otherwiſe the rays will proceed divergingly beyond that focus. It muſt likewiſe be recollected, in conſequence of what has been ſaid above of the conjugate foci of a lens, that if the conjugate foci are equidiſtant from the lens, then the image will be equal to the object; otherwiſe the ſize of the one will exceed that of the other, in proportion as the former is farther from the lens than the other. Or in other words, the lengths of the object and of the image are as their reſpective diſtances from the lens. Now with reſpect to the eye, it muſt not be imagined that the lens forms, by its refraction, an image of the object on the retina, in the ſame manner as it forms the image upon the ſcreen; becauſe from the lens towards the ſcreen the rays proceed convergingly; whereas, if they proceeded convergingly to the eye, the humours of that organ would converge them a great

great deal more than is neceſſary to form a focus or image upon the retina. But the real office of a lens that is adapted to the eye, is to render the rays of every ſingle radiant point parallel; for the eye receives thoſe parallel rays, and in virtue of its own refractive power, converges them to a focus, or forms an image of the object upon the retina.

Fig. 14, Plate XXI. repreſents an object A B ſituated at the principal focal diſtance of the lens E D: therefore, from what has been ſaid above, (page 218,) the rays which proceed from every ſingle radiant point, as A, or I, or B, or any other, fall divergingly upon the lens, and after having paſſed through it, proceed in a parallel direction, viz. the conical rays A D E proceed cylindrically, or become the parallel rays E P, C O, D W; the rays I D E become the parallel rays E F, C G, D H; and ſo on. Now if an eye be ſituated near the lens, and Q R be conſidered as the diameter of the pupil, it is evident in the firſt place, that the rays from every ſingle point of the object, enter the pupil in a parallel direction; ſecondly, the extreme rays, A E Q and B D R, enter the eye and limit the field of view; for the other rays, as A C O, A D W, &c. which come from the ſame extreme point A, do not enter the pupil Q R. Hence it is that if part of the lenſe's ſurface be covered, a portion of the object will likewiſe be rendered inviſible; or, which is the ſame thing, the field of view is proportionate to the aperture of the lens. Thirdly, it appears

appears that the object will be ſeen diſtinctly, whether the eye be placed nearer to or farther from the lens; but a ſmaller part of it will be ſeen when the pupil is farther off, as at S T, than when nearer, as at Q R; becauſe, when S T is the aperture of the pupil, the extreme rays A E P, B D M, which entered it at Q R, will not now enter it. Fourthly, with reſpect to the magnifying power, it muſt be obſerved that the axes of any two pencils, as for inſtance, the axes ACO, B C L, form an angle ACB at the centre of the lens, which is equal to the angle E *d* D, formed at the eye by the extreme rays A E *d*, B D *d*; which ariſes from the paralleliſm of the rays ACO, E *d*, and B C L, D *d*. Therefore the diſtance of thoſe two points, or the length of the object A B, will be ſeen under the ſame angle of viſion as if the naked eye were ſituated at C: but the naked eye cannot ſee an object diſtinctly at a diſtance leſs than 8 inches; therefore the eye at Q R, or at S T, will be enabled, by the action of the lens, to ſee the object A B enlarged; as if the naked eye itſelf, ſituated at C, ſaw the object at the diſtance C Y of 8 inches, and as large as Z X. So that the ſize of the image is to the ſize of the object as 8 inches is to the focal diſtance of the lens. Thus a lens, whoſe principal focal diſtance (or focus of parallel rays) is one inch, will magnify 8 times. If the focal length be half an inch, the lens will magnify 16 times, and ſo forth. In ſhort, to find the magnifying power of a lens, divide 8 inches (or the

the ſhorteſt diſtance of diſtinct viſion for any particular eye) by the focal length of the lens, and the quotient ſhews how many times the length or diameter of the image will exceed that of the object. The magnifying powers of lenſes are generally expreſſed by the length or diameter of the image, otherwiſe called the *lineal dimenſions.* Thus when a lens is ſaid to magnify the object four times, the meaning is, that the image, or the appearance of the object through the lens, is five times as long or as broad as the object itſelf. Some writers ſometimes reckon the magnifying power by the ſurface, and others even by the ſolidity. Thus ſpeaking of the ſame above-mentioned lens, it may be ſaid that it magnifies five times in length, or 25 times in ſurface, or 125 times in ſolidity; ſince the ſurfaces of ſimilar bodies are as the ſquares of their lengths, or of other like dimenſions, and their ſolidities are as the cubes of their lengths, or of other like dimenſions.

It has been mentioned above that the ſpherical curvature of lenſes does not converge the rays of the ſame radiant point exactly to one refracted focus, and that the aberration or indiſtinctneſs which ariſes therefrom, increaſes with the thickneſs of the lens and with the increaſe of curvature. But we muſt here farther obſerve, that from the properties of ſpherical ſurfaces, from the refraction of glaſs, &c. it has been demonſtrated by the writers on Optics, that the aberrations of lenſes, which have the ſame curvature but different apertures (viz. areas) are as the cubes of the apertures reſpectively; and that when the lenſes have equal apertures, then the aberrations are inverſely as the ſquares of the radii of curvature *. Whence it follows, that when large lenſes which do not magnify much, are uſed ſingly, the aberration is tolerable in moſt caſes; but when the lenſes have a conſiderable magnifying power, and are to be uſed for nice purpoſes, then the aberration or indiſtinctneſs is very detrimental.

In order to obviate this inconvenience, various contrivances have been offered; but the only one which anſwers the purpoſe to a conſiderable degree, is a combination of two ſhallow lenſes, ſet at a little diſtance from each other, which are uſed as a ſingle lens.

Fig. 15, Plate XXI. repreſents ſuch a combination of two lenſes; and they are plano-convex, ſince that figure admits of leſs aberration than any other. Let F be the focus of the ſingle lens N M; ſo that an object placed at F may be ſeen magnified through that lens. Now when the other lens G H is placed between the firſt lens and its focus, the rays which proceed from the object, by paſſing through both lenſes, are bent more than by a ſingle lens: hence the focus is ſhortened, viz. the focus of both conjointly will be at *f*; ſo that thoſe two

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* Martin's Optics, Art. 83.

lenſes act as a ſingle lens of a much greater curvature. But the advantage which the former have over the latter is, that the curvatures of the two lenſes conjointly are leſs than the curvature of the ſingle lens, that has an equal magnifying power; in conſequence of which leſs aberration and a larger field of view is obtained by the combination of the two lenſes.

The advantages of the two lenſes is derived from the ſpace which is left between them. In fact, by altering that diſtance the magnifying power is alſo altered. I ſhall not detain my reader with a long inveſtigation of the preciſe degree of aberration, field of view, and other particulars relative to the above-mentioned combination of lenſes. Whoever wiſhes to be informed particularly thereon, may by himſelf trace the rays of light through thoſe lenſes, after the manner which has been ſufficiently deſcribed in the preceding pages; or he may peruſe any of the principal works which have been written expreſsly upon Optics within theſe 50 or 60 years. I ſhall only add a rule neceſſary for determining the compound focus of ſuch lenſes; viz. *the focal lengths of two lenſes, and the diſtance between them, being given, to find the focal length of a ſingle lens that has the ſame magnifying power as the two combined lenſes.*

Rule. Subtract the diſtance from the ſum of the two focal lengths, and note the remainder; alſo multiply the two focal lengths together. Divide this product by the above remainder, and the quotient

quotient is the focal length of the ſingle lens as required.

Example. Let the focal length of one lens be 8 inches, that of the other be 6 inches, and let the diſtance between the two lenſes be 4 inches; then the ſum of the two focal lengths is 14 inches, from which ſubtract 4, and there remains 10. The product of 8 by 6 is 48, which, being divided by 10, quotes 4,8 inches; and this quotient is the focal length of a ſingle lens, which will have the ſame magnifying power as the combination of the two given lenſes; but not the ſame diſtinctneſs, nor ſo large a field of view.

CHAPTER VII.

DESCRIPTION OF THE PRINCIPAL OPTICAL INSTRUMENTS.

THE uſe of the ſimpleſt optical inſtruments, ſuch as lenſes, ſpectacles, reflectors, &c. has been ſufficiently explained in the preceding chapters; ſo that the inſtruments which remain to be deſcribed in the preſent chapter, are thoſe of a more complicated nature; viz. where the effect ariſes from the combination of two or more of the ſimple inſtruments.

One of the ſimpleſt and pleaſanteſt of thoſe inſtruments is the *camera obſcura*, the principle of which has been already deſcribed in elucidation of the conſtruction of the eye: but as in that camera obſcura the picture of the object is inverted, we muſt point out in what manner the image is rendered erect, and at the ſame time we ſhall deſcribe the moſt uſual conſtruction of a portable camera obſcura.

Of the Camera Obſcura.

Fig. 16, Plate XXI. repreſents a box conſiſting of two parts. The external ACBDEFG has a ſhutter

ſhutter or cover L N, which moves round an hinge PQ, and when open, as in the figure, it carries two lateral boards, which ſerve to exclude the light as much as poſſible from the rough glaſs O, which is diſcovered on opening the ſhutter L N P Q, and upon which the obſerver is to look. The fore ſide or part of the box is wanting, and in that aperture another narrower box E H I K G ſlides. This box wants the inner ſide, and has a convex glaſs lens fixed at I. If this machine be turned with the lens I towards any objects that are well illuminated, it is evident that an inverted picture of theſe objects will be formed within the box on the ſide A B C D; and that picture may be rendered diſtinct by moving the ſliding box E H G K in or out, in order to adjuſt the focus according to the diſtance of the external objects. Now at the back part of the box a flat piece of looking-glaſs is ſituated at an inclination of half a right-angle, as is ſhewn by the dotted lines B R; in conſequence of which the rays of light fall upon the looking-glaſs, and are reflected upwards to the rough glaſs O, which forms that part of the ſide of the box, which lies under the cover L N P Q. The picture then is formed upon that rough or ſemitranſparent glaſs, and will appear erect to a ſpectator ſituated behind the box, and looking down upon the glaſs O; becauſe that part of the picture, which falls upon the lower part of the looking-glaſs, is reflected to the upper part of the rough glaſs, viz.

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to the part next to the hinge P C, and *vice verſâ*, as may be eaſily conceived by the leaſt reflection.

The ſhape of the camera obſcura has been altered in a great variety of ways; ſometimes the looking-glaſs is placed before the lens, and the box is placed ſtraight up. In this conſtruction the rays are bent before they paſs through the lens, and the image or picture is formed within at the bottom of the box: hence in order to view it, one lateral ſide of the box is cut off, and the obſerver looks at the picture through that opening, or introduces his hand through it for the purpoſe of drawing an outline of the picture.—N. B. A curtain of ſome dark ſtuff muſt be laid over the obſerver, in order to prevent the introduction of any extraneous light.

Of the Magic Lantern.

Fig. 1, Plate XXII. repreſents the machine, with the effect it produces. By means of this inſtrument ſmall coloured images painted upon glaſs are conſiderably magnified, and thrown upon the wall of a dark room, in their natural and vivid colours, to the great entertainment of the by-ſtanders, eſpecially of children.

Fig. 2, ſhews the internal parts of the machine fig. 1, placed at their proportionate diſtances. The lantern contains a candle A, or ſometimes two, or three, or more burners placed cloſe to each other;

other; a reflector M N, which is ſo ſituated as to have the light A in its focus. On the fore part of the lantern there is a thick double convex lens C D, or a plano-convex (uſually called a *bull's eye*) of ſhort focus. The lantern is cloſed on every ſide, ſo that no light can come out of it, but what paſſes through the lens C D. In the direction of this lens there is a tube, or apparatus, fixed to the lantern, which has a lateral aperture from ſide to ſide, through which the glaſs ſlider with the painted ſmall images, is moved in an inverted poſition. G H repreſents one of theſe images. The fore part of the tube contains another ſliding tube, which carries the double convex lens E F. The effect of thoſe parts is as follows:

The thick lens C D throws a great deal of light from the candle A upon the image G H. And to increaſe that light ſtill more, the reflector M N is often, but not always, placed in ſuch lanterns; for as the flame is in the focus of the reflector, the light proceeds in parallel lines from the reflector to the lens C D. The image G H being thus well illuminated, ſends forth rays from every point, which, by paſſing through the lens E F, are converged to a focus upon the wall, and form the large image, as is ſhewn in fig. 1.

What has been ſaid above of the conjugate foci of a lens will ſhew the neceſſity of moving the lens E F nearer to, or farther from, the painted image

G H, according to the diſtance of the wall; and does likewiſe ſhew why is the repreſentation upon the wall ſo much larger than the painted image G H.

In ſome magic lanterns, inſtead of the ſingle lens E F, two lenſes are uſed of leſs curvature, and ſet at a little diſtance from each other; which act rather better than a ſingle lens. See fig. 3, where *bb* is a diaphragm.

Of Dioptric Teleſcopes.

The magnifying powers of lenſes have been ſhewn to be inverſely as their principal focal lengths; from which it follows, that very diſtant objects are not ſenſibly magnified by the interpoſition of a ſingle lens; but that effect may be produced by a combination of two or more lenſes, as alſo by a combination of reflectors and lenſes. The former are called *dioptric teleſcopes*, and the latter are called *catadioptric*, or *reflecting teleſcopes*.

The dioptric teleſcope, from the various combination of its lenſes, as alſo from its principal uſes, derives different appellations; viz.

The *aſtronomical teleſcope*, (which conſiſts of two convex lenſes, AB, KM, fig. 4, Plate XXII.) fixed at the two extremities of a tube, which conſiſts at leaſt of two parts that ſlide one within the other, for adjuſting the focus in proportion to the diſtance of the objects that are to be ſeen through the teleſcope [*].

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[*] The tube is not repreſented in the figure.

P Q repreſents the ſemidiameter of a very diſtant object, from every point of which rays come ſo very little diverging to the object lens K M of the teleſcope, as to be nearly parallel. —*p q* is the picture of the object P Q, which would be formed upon a ſcreen ſituated at that place. Beyond that place the rays of every ſingle radiant point proceed divergingly upon another lens A B, called the eye glaſs, which is more convex than the former, and are by this cauſed to proceed parallel to one another, in which direction they enter the eye of the obſerver at O.

The two lenſes of this teleſcope have a common axis O L Q; L*q* is the focal diſtance of the object lens, and E*q* is the focal diſtance of the eye lens. E L is the ſum of both focal diſtances. An object viewed through this teleſcope, by an eye ſituated at O, will appear diſtinct, inverted, and magnified; viz. the object ſeen without the teleſcope will be to its appearance through the teleſcope, as *q* E to *q* L; that is, as the focal diſtance of the eye lens to the focal diſtance of the object lens.

For the rays which, after their croſſing at the place *r q p*, proceed divergingly, fall upon the lens A B in the ſame manner as if a real object were ſituated at *r q p* (viz. at the focus of that lens); and of courſe on the other ſide of that lens the rays of each pencil will proceed parallel (ſee what has been ſaid of a ſingle lens in p. 228, 231.) Now to the eye at O, the apparent magnitude of the object, or

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of the part P Q, is meaſured by the angle EOA, or by its equal q E p; but to the naked eye at L, when the glaſs is removed, the apparent magnitude of the object is meaſured by the angle QLP, or by its equal q L p; therefore the apparent magnitude to the naked eye is to the apparent magnitude through the teleſcope, as the angle q L p is to the angle q E p; or as the diſtance q E is to the diſtance q L.

This teleſcope is moſtly uſed for aſtronomical obſervations; for as it inverts the object, the repreſentation of terreſtrial objects through it would not be pleaſant.

It is evident from the above explanation, that if the two lenſes of this teleſcope have equal focal diſtances, the teleſcope will not magnify. It alſo appears that, with a given object lens, the ſhorter the focus of the eye lens is the greater will the magnifying power be. But when the diſproportion of the two focal lengths is very great, then the aberration ariſing from the figure of the lenſes and from the diſperſive power of glaſs, becomes ſo very great as to do more damage than can be compenſated by the increaſed magnifying power. Hence, in order to obtain a very great magnifying power, thoſe teleſcopes have ſometimes been mad every long, as for inſtance of 100 feet, or upwards: and as they were uſed for aſtronomical purpoſes, or moſtly in the night time, they were frequently uſed without a tube, viz. the object lens was fixed on the top of a pole in a frame capable

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of motion in any required direction, and the eye lens was fixed in a ſhort tube that was held in the hand of the obſerver. The diſtance as well as the direction of the two lenſes was adjuſted by a ſtrong cord ſtretched between the frame of the object lens and the tube of the eye lens.

In this conſtruction the inſtrument has been called an *aërial teleſcope.* Its uſe is evidently incommodious; but it was with ſuch a teleſcope that five ſatellites of ſaturn, and other remarkable objects were diſcovered.

The imperfections of ſuch a teleſcope ariſe principally from the diſperſive power of glaſs, which, eſpecially at the edge of the field of view, frequently introduces circles of priſmatic colours: but ſince the invention of achromatic lenſes, the teleſcopes have been made much ſhorter, by ſubſtituting either a double or a triple achromatic lens in lieu of a ſimple object lens K M; for with an achromatic lens the bad effect of the diſperſion is in great meaſure, if not entirely, removed.

In a teleſcope of a given length, the quantity of object which is taken in at once, or the field of view, depends upon the breadth of the eye lens; for as AE is larger or ſmaller, ſo the angle ALE or its equal PLQ, is larger or ſmaller (ſee page 264); and this angle takes in all the object, or the part of an object that can be ſeen at one view on one ſide of the axis of the teleſcope. But in order to increaſe the field of view as much as poſſible, and in great meaſure the magnifying power alſo, the eye lens, or what performs the office of a ſingle lens, as is now uſed, conſiſts of two plano-convex lenſes, ſet at a little diſtance from each other. The advantage of ſuch a combination has been explained in page 267.

The object, which appears inverted through the above-deſcribed teleſcope, will appear upright and diſtinct, if two more convex eye glaſſes be ſubjoined to it, as in fig. 5, Plate XXII. which repreſents the ſame teleſcope as that of fig. 4, but with the addition of two other convex lenſes B, C, ſituated at a diſtance from each other, which is equal to the ſum of their focal diſtances; and when their focal diſtances are equal, the object will be magnified as much as without thoſe additional glaſſes; but through them it will appear ſtraight up or rectified, and not inverted. Hence this teleſcope has been moſtly uſed for viewing terreſtrial objects, and is therefore called the *terreſtrial teleſcope* or *perſpective glaſs.*

For the pencils of rays E O F, A O B, &c. that are continued to the lens F B, will be formed by it into a ſecond image S T; and the focus S of any oblique pencil O B, will be determined by the interſection of the line S T, perpendicular to the common axis of the lenſes, and of the oblique axis F S, drawn parallel to the incident rays O B. This point S being the focus of incident rays on the laſt lens G C, the emergent rays C D will be parallel to the oblique axis S G, becauſe the rays which proceed from T are ſuppoſed to emerge parallel to the

the direct axis; therefore to the eye at D the object will appear diſtinct and upright.

When the lenſes B, C, are quite equal, then the angle CDG, which now meaſures the apparent magnitude of the object, is equal to the angle AOE; hence, &c.

The laſt lens, or the one neareſt to the eye in this teleſcope, is now moſtly made double; viz. inſtead of one, two lenſes are combined together, for the purpoſe of enlarging the field of view (ſee page 267): hence moſt of the terreſtrial teleſcopes now contain four lenſes in the tube next to the eye.

The *Galilean teleſcope* conſiſts of a convex object lens, and a concave eye lens; and derives its name from the great Galileus, who is generally reckoned the inventor of it. See fig. 6, Plate XXII. which ſhews that the diſtance between the two lenſes is leſs than the focal diſtance of the object lens; viz. inſtead of the convex lens ſituated behind the place of the image, to make the rays of each pencil proceed in a parallel direction to the eye, here a concave eye lens is placed as much before that image; and this lens opens the rays of each pencil that converged to *q* and *p*, and makes them emerge parallel towards the eye; as is evident by conceiving the rays to go back again through the eye lens, whoſe focal diſtance is E *q*.

The eye muſt be placed cloſe to the concave lens, in order to receive as many pencils as poſſible; and then ſuppoſing an emerging ray of an oblique pencil to be produced backwards along AO, the apparent magnitude of the object is meaſured by the angle AOE, or its equal qEp, which is to the angle qLp (or QLP, the meaſure of the magnitude) as qL to qE, viz. as in the aſtronomical teleſcope. It is evident that in this teleſcope the objects appear erect, for the rays of light do not croſs each other.

The field of view or quantity of objects that are taken in at once in this teleſcope, does not depend upon the breadth of the eye lens, as in the aſtronomical teleſcope, but upon the breadth of the pupil of the eye; becauſe the pupil is leſs than the eye lens AB, and the lateral pencils do not now converge to, but diverge from, the axis of the lenſes. Upon this account the view is narrower in this than in the preceding teleſcope; yet the objects through it appear remarkably clear and diſtinct.

An achromatic object lens, inſtead of the ſimple lens KL, improves this as well the preceding teleſcopes.

The common *opera glaſs* is nothing more than a ſhort Galilean teleſcope.

The *night teleſcope* is a ſhort teleſcope, viz. about two feet long, which repreſents the objects inverted, much enlightened, but not much magnified. Its field of view is alſo very extenſive.

This teleſcope, in conſequence of thoſe properties, is uſed at night moſtly by navigators, for the purpoſe of diſcovering objects that are not very diſtant, but which cannot otherwiſe be ſeen for want of ſufficient light; ſuch as veſſels, coaſts, rocks, &c. On account of its extenſive field and great light, this teleſcope has alſo been advantageouſly uſed by aſtronomers for diſcovering ſome cœleſtical objects, whoſe ſituation was not exactly known, or for viewing at once the relative ſituation of ſeveral ſtars and other objects.

This teleſcope has a pretty large and ſimple object lens, whence it derives its great light; for as the rays which proceed from every ſingle point of the object, fall upon the whole lens of a teleſcope, and are thence refracted to a focus, it is evident that the larger that lens is, the greater number of rays will be thrown upon that focus; and of courſe the brighter will the image be. In this teleſcope a pretty large lens may be uſed, becauſe the teleſcope is not intended to magnify more than about four or ſix times in lineal extenſion.

Within this teleſcope a ſecond lens is often uſed for ſhortening the focal length of the object lens. The eye lens is ſometimes ſingle, but moſtly double, (viz. a combination of two plano-convex lenſes placed at a little diſtance from each other) and pretty large; hence is derived the extenſive field of view, which in ſome of thoſe teleſcopes exceeds ſix or ſeven degrees.

We may obſerve once for all, that in every teleſcope the diſtance between the object lens and the other lens or lenſes muſt be alterable, in order that the

the focus may be adjuſted according to the diſtance of the objects. Hence, every teleſcope conſiſts at leaſt of two tubes, one of which, viz. that with the eye lenſes, ſlides within the other. To the ſame teleſcope ſeveral eye tubes, with a ſhallower or deeper lens, or with a different number of lenſes, may be adapted ſucceſſively, in order to give them different magnifying powers, ſuitably to the clearneſs of the air, of the objects, &c. as alſo for converting them into aſtronomical or terreſtrial teleſcopes.

Of the Catadioptric Teleſcope.

This is likewiſe called the *Newtonian teleſcope*, or *reflecting teleſcope*; for if not the original projector, Sir Iſaac Newton is, at leaſt, the firſt perſon who executed a teleſcope of this ſort, which, as its name imports, conſiſts of reflecting and refracting parts.

The general principle of this teleſcope is the ſame as that of the dioptric or refracting teleſcope. In the latter the rays which come from a diſtant object are, by the action of the convex object lens, collected to a focus, and beyond that focus the rays of every ſingle radiant point are rendered again parallel by the action of the eye lens or eye lenſes. This is otherwiſe expreſſed, by ſaying that the object lens forms an image of the object, which image is viewed by the eye lens. In the former, viz.

viz. in the reflecting teleſcope, the rays which come from a diſtant object, are, by the action of a concave reflector, ſent back convergingly to a focus, where they form an image, which is viewed through the eye lens.

There are four varieties of this teleſcope, which will be eaſily comprehended.

Fig. 7, Plate XXII. repreſents the principle of the original conſtruction. ACDB is the ſection of a tube open at AB. EF is a concave reflector fixed at the bottom of the tube; *m n* is an arm projecting from one ſide of the tube, as far as its middle or axis, where it ſupports a ſmall flat ſpeculum G, ſet aſlant*; ſo that the rays which come from every ſingle point of a diſtant object IK, and fall upon the concave ſpeculum EF, are reflected by it in a converging manner to the ſmall flat ſpeculum G, which bends their courſe ſideway, and ſends them with the ſame convergency to an hole at H in the ſide of the tube, where the image of the object IK is formed; and this image is viewed by the eye through an eye lens L, or through a tube with more than one eye lens, for the purpoſe of repreſenting the object erect, as in the above-deſcribed refracting teleſcopes.

It is evident that the focal length of the ſpeculum

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* Inſtead of the flat ſpeculum, a glaſs priſm has been often applied, which, in a certain ſituation, acts like a reflector. See page 192.

is equal to E G plus G H; for the flat reflector G does only bend the rays ſideway. Without that ſmall reflector, the rays reflected from E F, would form an image at O (O G being equal to G H) where indeed an eye lens might be placed, and the obſerver looking through it, with his face towards the reflector E F, would ſee the magnified image of the object I K; but in that caſe the head of the obſerver would intercept a great part of the rays; yet, by ſetting the reflector E F a little aſlant, its focus may be thrown to P, where the eye lens being applied, the head of the obſerver would obſtruct little or none of the light, eſpecially when the reflector F E is of a conſiderable ſize. This forms the ſecond variety.

The magnifying power of this teleſcope is determined after the ſame manner as in the refracting teleſcope, viz. the focal length of the reflector E F (which is analogous to the object lens of the refracting teleſcope) is divided by the focal length of the eye lens, and the quotient ſhews how many times the object ſeen through the teleſcope appears larger (meaning in lineal extenſion) than without the teleſcope.

In this teleſcope there is an adjuſtment at H, viz. the ſhort tube with the eye lens, or lenſes, may be ſlid a little way in or out; for the focal diſtance of the reflector E F increaſes or decreaſes according to the diſtance of the object.

The third variety is called the *Gregorian teleſcope*, and

and is repreſented in fig. 8, Plate XXII. The large concave ſpeculum BE of this teleſcope is perforated with a hole quite through its middle. Within the tube of the teleſcope a ſmall concave ſpeculum *xy*, is ſupported by the arm H, directly facing the large ſpeculum B E. Two lenſes, W X and *n o*, are contained in the eye tube, and the obſerver applies his eye to a ſmall hole at P, in order to view the magnified diſtant object G.

The large reflector B E receives the rays *a c*, *b d*, from the diſtant object, and reflects them to its focus *e*, where they form the inverted image, or where they croſs each other, and then fall divergingly upon the ſmall reflector *xy*, whoſe focus is at *f*; viz. a little farther than the focus *e* of the large reflector: hence the rays are reflected back upon the lens W X, not in a parallel, but in a converging manner; and that convergency is increaſed by the action of that lens, ſo as to come to a focus, or to form a ſecond image RS much larger than the former, and erect like the object. Laſtly, this image is viewed through the eye lens *n o*; or, in other words, the rays from every ſingle point of the object, after this ſecond croſſing, fall divergingly upon the eye lens, which ſends them nearly parallel to the eye at P, through a very ſmall hole. Sometimes the eye lens *no*, is double, viz. it conſiſts of two lenſes, which perform the office of a ſingle lens, as has been explained above (page 267).

If the firſt lens WX were removed, the image would be formed ſomewhat larger at *z*; but the area or field of view would be ſmaller and leſs pleaſant. At the place of the image R S, there is ſituated a circular piece of braſs, called a *diaphragm*, with a hole of a proper ſize to circumſcribe the image, and to cut off all ſuperfluous or extraneous light, in order that the object may appear as diſtinct as poſſible.

The magnifying power of this teleſcope is computed in the following manner:

If this teleſcope conſiſted of the two reflectors only, and theſe were ſituated ſo that *e* were the focus of each reflector; then the rays which came parallel from the diſtant object to the large reflector, and divergingly from that to the ſmall reflector, would, after the ſecond reflection, go parallel to the eye at P, and of courſe the object would appear magnified in the proportion of the focal diſtance of the large reflector to the focal diſtance of the ſmall reflector; ſo that if the focal diſtance of the former be to that of the latter as 6 to 1, then the object would be magnified 6 times in diameter. But ſince the firſt image is magnified into a ſecond image much larger, which is viewed through the eye lens; therefore the whole magnifying power is in a proportion compounded of *de* to *ex*, and of *xz* to *zo*. If the former proportion be as 6 to 1, and the latter as 8 to 1; then the object will appear 48 (viz. 6 by 8) times larger in diameter through the teleſcope than to the naked eye.

The fourth ſpecies of reflecting teleſcope goes under the name of *Caſſegrainian teleſcope*. It differs from the preceding, in having the ſmall reflector convex, inſtead of concave; in conſequence of which the ſmall reflector muſt be placed nearer to the large reflector than the focus of the latter; then the rays from the large reflector fall convergingly upon the convex ſmall reflector, and are by it ſent back convergingly upon the lens W X, &c.

The only difference that is worth remarking between this and the preceding teleſcope is, that in this the object appears inverted, becauſe in it there is no image formed, or the rays do not croſs each other, between the two reflectors. Alſo with the ſame magnifying power, &c. this teleſcope is ſhorter than the Gregorian, by twice the focal length of the ſmall ſpeculum.

To both thoſe teleſcopes a long wire is fixed all along the outſide of the tube, at the end of which there is a ſcrew which works into an external projection *g* of the internal arm H, and ſerves to move that arm with the ſmall ſpeculum nearer to or farther from the large ſpeculum, in order to adjuſt the focus of the inſtrument, according to the diſtance of the object. The action of this wire is eaſily underſtood; for it paſſes through a hole at F, where it is prevented going forwards or backwards by two ſhoulders, which are indicated by the figure: hence, when the obſerver looks through the hole P, he turns with his hand the wire by the nut Q, which ſcrews the projection *g* of the arm nearer or farther, &c. until the object appears very diſtinct.

Upon the whole, the reflecting teleſcopes may be rendered more powerful than the refracting teleſcopes of the ſame length; which ariſes principally from the rays of light not being diſperſed by reflection as they are by refraction, and likewiſe from the practicability of giving the large reflectors a form either parabolical, or at leaſt ſuch as anſwers better than the ſpherical figure*. But the reflecting teleſcopes are larger and heavier than the refractors; hence, when ſhort and portable teleſcopes are wanted, the achromatic teleſcopes may be preferred; but for aſtronomical obſervatories, where large and very powerful teleſcopes are wanted, the reflectors ſhould be preferred.

The largeſt reflecting teleſcope now exiſting, was conſtructed by that excellent aſtronomer, Dr. Herſchel. It is a teleſcope of the ſecond ſpecies,

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* If the reader wiſh to learn the method of forming, poliſhing, &c. the reflectors of thoſe teleſcopes, which are univerſally made of metal, he may conſult Dr. Smith's Optics, Book III. Chapter II.; Mudge's Paper in the 67th Volume of the Philoſophical Tranſactions; the Rev. John Edwards's Directions for making the beſt Compoſition for the Metals of reflecting Teleſcopes, &c.

viz. where the obſerver looks through an eye lens down upon the large reflector, whoſe poliſhed ſurface is 48 inches in diameter. Its focal length is about 40 feet*; and I do not know that a refracting teleſcope was ever made, whoſe power equalled that of this gigantic teleſcope, or of another of 20 feet, which was conſtructed and uſed by the ſame perſon, or even of one of his ſeven feet reflectors, to which Dr. Herſchel can give a magnifying power of ſome thouſands †.

The above-mentioned methods of computing the magnifying powers of toleſcopes, are not in general very practicable, as the lenſes and ſpeculums cannot eaſily be removed from the teleſcopes, in order to have their particular focal diſtances aſcertained; therefore it will be proper to ſhew how this object may be accompliſhed experimentally.

There are ſeveral experimental methods of aſcertaining the magnifying powers of teleſcopes ‡; but I ſhall ſubjoin one of the eaſieſt, which is deſcribed by the Rev. John Edwards in the following words: "At the diſtance of 100 or 200 yards from the "teleſcope, put up a ſmall circle of paper, of any "determined diameter, an inch for inſtance. Upon

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* Phil. Tranſ. vol. for 1795. Art. XVIII.

† Phil. Tranſ. vol. 72, Art. XI.

‡ See Dr. Smith's Optics, Notes to Art. 109 and 485. Alſo, my Deſcription and Uſe of the mother-of-pearl Micrometer, London 1793.

" a card, or any piece of ſtrong paper, through " which the light cannot be eaſily tranſmitted, draw " two black parallel lines, whoſe diſtance from " each other is exactly equal to the diameter of the " ſmall circle. Adjuſt the teleſcope to diſtinct " viſion, and through it view the aforeſaid ſmall " circle with one eye, and with the other eye, open " alſo, view at the ſame time the two parallel lines. " Let the parallel lines be then moved nearer to, or " farther from your eye, till you ſee them appear " exactly to cover the ſmall circle viewed in the " teleſcope. Meaſure now the diſtance of the " ſmall circle, and alſo of the parallel lines, from " your eye. Divide then the diſtance of the " former by that of the latter, and you will " have the magnifying power of the teleſcope re" quired."

In the preceding pages we have taken no notice of the tubes, ſtands, and movements that are uſually given to teleſcopes; firſt, becauſe thoſe particulars are not neceſſary for illuſtrating the principles of optical inſtruments; and ſecondly, becauſe the particular deſcription of thoſe external parts, in all their variety, would require a great many more pages than can poſſibly be allotted to it in theſe elements. There are however two uſeful appendages to teleſcopes, which deſerve to be briefly deſcribed.

A *finder*, viz. a ſhort teleſcope A, fig. 8, is generally affixed to the tube of a large teleſcope, for the purpoſe

poſe of finding out an object expeditiouſly. This finder does not magnify the object more than 4, 6, or 8 times; but it has a great field of view, ſo that through it a great part of the heavens may be ſeen at once. In the inſide of its tube, and exactly at the focus of the eye glaſs, there are two ſlender wires, which croſs each other in the axis of the teleſcope. Now the finder is adjuſted by means of ſcrews upon the tube of the great teleſcope, in ſuch a manner as that when an object, ſeen through the finder, appears to be near the croſſing of the above-mentioned wires, it is at the ſame time viſible through the great teleſcope: hence, when the obſerver wiſhes to view a ſmall diſtant object, as a ſtar, a planet, &c. he moves the inſtrument to one ſide or the other, until, by looking through the finder, he brings the object nearly to coincide with the croſſing of the wires, and when that takes place, he immediately looks through the large teleſcope, &c.

A *micrometer* is an inſtrument, which is uſed with a teleſcope, for the purpoſe of meaſuring ſmall angles. A great variety of micrometers have been contrived by various ingenious perſons; and they are more or leſs complicated, more or leſs expenſive, as alſo more or leſs accurate. If the reader wiſh to examine the conſtruction of any of the various micrometers, he may peruſe the works that are mentioned in the note *. I ſhall only ſubjoin the deſcription of a very ſimple, and, at the ſame time, accurate micrometer, which I contrived ſome years ago; but we may previouſly obſerve, that in general the micrometers meaſure the ſize of the image, which is formed in the focus of the eye lens or of the eye lenſes within the teleſcope; for knowing the magnifying power of the teleſcope, one may eaſily calculate to what angle ſuch meaſurement correſponds. For inſtance, if the teleſcope magnify 30 times, and the length of the image of the object is ſhewn by the micrometer to ſubtend an angle of two minutes; then we may conclude that the real object ſubtends an angle of the 30th part of two minutes, viz. an angle of four ſeconds; and ſo on.

My micrometer conſiſts of a ſmall ſemitranſparent ſcale or ſlip of mother-of-pearl, about the 20th part of an inch broad, and of the thickneſs of common writing paper. It is divided into a number of equal parts

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* Dr. Smith's Optics, Book III. Chapter VIII. for the earlieſt micrometers. Dollond's Micrometer, Phil. Tranſ. vol. 61, p. 536. Boſcovich's Micrometer, Phil. Tranſ. vol. 67, p. 789, 799. Rochon's Micrometers; his *Recueil de Mem. ſur la Mecanique et la Phyſique.* Ramſden's Micrometers, Phil. Tranſ. vol. 69, p. 419. Herſchel's Lamp-Micrometer, Phil. Tranſ. vol. 72. Art. XIII. Smeaton's Equatorial Micrometer, Phil. Tranſ. vol. 77. Art. XXXIII.

parts by means of parallel lines, every fifth and tenth of which diviſions is a little longer than the reſt.

This micrometer, or divided ſcale, is ſituated within the tube at the focus of the eye lens of the teleſcope, where the image of the object is formed, and with its divided edge paſſing through the centre of the field of view; though this is not abſolutely neceſſary. It is immaterial whether the teleſcope be a refractor or a reflector, provided the eye lens be convex, and not concave, as in the Galilean teleſcope.

The ſimpleſt way of fixing it, is to ſtick it upon the diaphragm, which generally ſtands within the tube, at the focal diſtance of the eye lens.

By looking through the teleſcope, the image of the object and the micrometer will appear to coincide: hence the obſerver may eaſily ſee how many diviſions of the latter meaſure the length or breadth of the former; and knowing the value of the diviſions of the micrometer, he may eaſily determine the angle which is ſubtended by the object.

There are ſeveral methods of aſcertaining the value of the diviſions of a micrometer in a given teleſcope. The following is one of the eaſieſt.

Direct the teleſcope to the ſun, and obſerve how many diviſions of the micrometer meaſure its diameter exactly; then take out of the Nautical Almanack the diameter of the ſun for the day in which the obſervation is made; divide it by the above-mentioned

mentioned number of diviſions, and the quotient is the value of one diviſion of the micrometer. Thus, ſuppoſe that 26½ diviſions of the micrometer meaſure the diameter of the ſun, and the Nautical Almanack gives for the meaſure of the angle, which is ſubtended by the ſame diameter, 31′, 22″, or (by reducing it all into ſeconds) 1882″. Divide 1882″ by 26,5, and the quotient, neglecting a ſmall remainder, is 71″, or 1′, 11″; which is the value of one diviſion of the micrometer; the double of which is the value of two diviſions; the treble is the value of three diviſions; and ſo forth *.

The *Microſcope* is another moſt uſeful, inſtructive, and pleaſant optical inſtrument. As the teleſcope enables us to diſtinguiſh objects, or the parts of objects that are otherwiſe inviſible on account of their being too remote from us; ſo the microſcope enables us to perceive ſuch ſmall objects and their parts, as are otherwiſe abſolutely inviſible to us.

It has already been obſerved, that there are two ſorts of microſcopes, viz. the ſimple, which conſiſts of one lens, and the compound, which conſiſts of

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* For farther particulars relative to this mother-of-pearl micrometer, ſee the Philoſophical Tranſactions, vol. LXXXI. Art. XIX. or its ſeparate deſcription publiſhed in London in the year 1793, wherein other methods are deſcribed of aſcertaining the value of its diviſions, when the teleſcope does not take in the whole diſc of the ſun.

more than one lens. The *ſolar* and the *lucernal* microſcopes are ſometimes conſidered as two other ſpecies of microſcope; but in truth they are only ſimple microſcopes, wherein the objects are illuminated either by the ſun's light or by a lamp, candle, &c.

Of the properties of the ſimple microſcope, viz. of the magnifying power, &c. of a ſingle ſmall lens, ſufficient mention has been made in the preceding pages. We ſhall only obſerve with reſpect to its limits, that ſmall lenſes have been made, whoſe focal diſtance was ſhorter than one 200th part of an inch, and which of courſe magnify the object upwards of 1600 times in diameter; but very ſeldom any ſuch lens turns out ſufficiently well ſhaped and well poliſhed. Globules of glaſs have alſo been conſtructed by means of a lamp and blow-pipe, whoſe diameter was about the 1000th part of an inch, and of courſe their magnifying powers were prodigiouſly great. But ſuch ſmall lenſes or globules are managed with very great difficulty; their field of view is extremely ſmall, and, as the object muſt be brought exceedingly near their ſurface, they are thereby eaſily dirtied or ſcratched, and conſequently rendered uſeleſs. It muſt be acknowledged, however, that through a ſingle lens, when it is well ſhaped and well poliſhed, an object appears much clearer and more diſtinct, though a little more diſtorted, than through a compound microſcope of equal magnifying power.

Fig. 9, Plate XXII. repreſents the two lenſes of a compound microſcope. *acb* is a ſmall object, placed not preciſely at, but near the focus of the ſmall object lens *def*, and the rays of light which proceed from any ſingle point of the object, are by the action of that lens converged to a focus ſomewhere about ABC, where an image is formed, which is larger than the object, in proportion as the diſtance B*e* exceeds the diſtance *ec*. Another larger lens DF is ſituated ſo that its focus may be at B; then the eye of the obſerver at I will view the image AC, magnified by that large lens DF; or in other words, the rays which proceed from each ſingle point, for inſtance *c* of the object, by paſſing through the lens *df*, are converged to a focus B, where they croſs each other, and then proceed divergingly through the eye lens DF, which cauſes them to proceed nearly parallel to the eye.

The magnifying power of this microſcope is eaſily computed; for firſt of all, the image AC is to the object as the diſtance B*e* is to the diſtance *ce*; and ſecondly, the image AC will be ſeen by the eye at I, under the angle DIF, which is equal to the angle AEC; and therefore that image will appear as much longer than to the naked eye, as the diſtance BE is ſhorter than 8 inches (or the limit of diſtinct viſion with the naked eye); ſo that if the diſtance *ec* be one inch, *e*B ſix inches, and EB two inches, then the image AC is ſix times longer than the object *ab*, and that image is magnified four times by the lens DF; ſo that upon the

whole,

whole, to the eye at I the object *a b* will appear magnified 4 times 6, or 24 times.

This microſcope has a larger field of view than a ſimple microſcope of the ſame power; and its field of view is rendered larger ſtill by the addition of one or two more lenſes inſtead of the ſingle lens D F. The magnifying power of the inſtrument, with more than two lenſes, muſt be computed from the effect of all the lenſes; or it may be aſcertained experimentally in the following manner. Place part of a divided ruler before the microſcope, ſo that, looking through the inſtrument, you may ſee one of its diviſions magnified; then open the other eye alſo, and looking with it at the ruler out of the microſcope, you will perceive the image of the magnified diviſion as it were projected upon the ruler; and you may eaſily ſee how many diviſions of the unmagnified ruler meaſure, or are equal to, the ſingle magnified diviſion, and that number is the magnifying power of that microſcope. Thus, if the ruler be divided after the common way into inches and tenths, and if you find that one magnified tenth is equal to three inches, you may conclude that the microſcope magnifies 30 times.

Different ſhapes, and likewiſe different uſes, of the ſimple or compound microſcope, have given thoſe inſtruments a variety of names, which, in truth, are dependent not upon the principle, but upon the apparatus, which is neceſſary either to render it portable, or ſteady, or applicable to any

particular

particular purpoſe. Thus, we hear of the *aquatic microſcope*, *opaque microſcope*, (viz. for viewing opaque objects) *Wilſon's microſcope*, &c.

Microſcopes have been alſo made by means of reflectors; hence they are called *reflecting microſcopes*. The principle of their conſtruction may be eaſily derived from what has been ſaid above with reſpect to the reflecting teleſcope. But, upon the whole, reflecting microſcopes are neither ſo uſeful nor ſo manageable as thoſe with lenſes.

Micrometers have been applied to compound microſcopes, as well as to teleſcopes, and generally in the ſame manner, viz. at the place where the image is formed within the body of the microſcope. There are however ſome micrometers applied to the object itſelf; viz. the object is laid upon a divided ſlip of glaſs, of ivory, or of metal, &c. and are both magnified at the ſame time. But theſe micrometers are by no means ſo eaſy of application, nor ſo generally uſeful, as thoſe which meaſure the image within the microſcope; amongſt which the mother-of-pearl micrometer (ſuch as has been deſcribed above for the teleſcope) is by far the moſt accurate, as well as the ſimpleſt. It is only neceſſary to obſerve, that with the microſcope this micrometer meaſures the lineal dimenſions of the object; and the value of its diviſions are aſcertained by placing an object of a known dimenſion before the microſcope, and by obſerving how many diviſions of the micrometer meaſure its magnified image; for inſtance,

inſtance, place a piece of paper, which is exactly one-tenth of an inch long, before the microſcope, and if you find that 50 diviſions of the micrometer meaſure its magnified image, you may conclude that each diviſion is equal to, or rather denotes an extenſion of the 500th part of an inch in the object; for if 50 diviſions meaſure one-tenth, 500 diviſions muſt meaſure the whole inch; and ſo forth.

The laſt inſtrument which I ſhall mention in this chapter, is called *photometer*, or meaſurer of light; its office being to indicate the different quantities of light; for inſtance, in a cloudy or bright day, or between different luminous bodies. But as a commodious inſtrument of this ſort is rather a *deſideratum* in philoſophy; I ſhall only mention in general terms, that the ratio of the intenſities of two luminous objects have been attempted to be meaſured by placing them at different diſtances from a given object, until that object caſt two ſhadows of equal darkneſs; or by obſerving when two equal objects appeared to be equally illuminated, each by one of the luminous objects; for then the proportion of the intenſities of their lights was reckoned to be as that of the ſquares of the diſtances. For inſtance, if two equal objects appear to be equally illuminated, when one of them is three feet from a tallow candle, and when the other is nine feet from a wax candle; then it is concluded that the intenſity of the light

light of the tallow is to that of the wax candle as 9 to 81*.

The intenſity of light has alſo been meaſured by means of an extremely ſenſible thermometer, and the contrivance is a very curious one †; but this proceeds upon the ſuppoſition that heat and light are the ſame thing, or that they are always accompanied in equal degree; or that the ſame quantity of light does always excite the ſame quantity of heat; which is not the caſe.

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* See Count Rumford's Paper in the Philoſophical Tranſactions, Volume for the year 1794. Art. IX. as alſo Prieſtley's Hiſtory of Light, Colours, and Viſion; P. VI. Sect. VII.

† Nicholſon's Journal of Natural Philoſophy, Chemiſtry, &c. vol. III. pages 461, and 518.

CHAPTER VIII.

NATURAL PHENOMENA RELATIVE TO LIGHT.

WE have reſerved for this chapter the account of ſuch natural phenomena reſpecting light, as could not be inſerted in the preceding chapters, without interrupting the general theory of optics.

The *rainbow* is undoubtedly the moſt frequent, the moſt remarkable, and the more generally known, of thoſe phenomena. We ſhall, in the firſt place, ſtate the particular circumſtances that attend its appearance, and ſhall then ſubjoin the uſual explanation, which is derived from the above deſcribed theory of optics.

When the ſun is on one ſide of the ſpectator, and rain falls on the other ſide, a beautiful coloured arch is frequently ſeen in the ſky on the ſide of the rain. This coloured arch is called the *rainbow*; and often two ſuch arches are ſeen one within the other, as in fig. 10, Plate XXII.

The colours of the inner bow EABF, are much more vivid than thoſe of the outer bow GCDH. Each bow exhibits all the priſmatic colours, arranged in the ſame order as in the priſmatic ſpectrum, viz. red, orange, yellow, green, blue, indigo, and violet; but the order of thoſe colours in the upper bow is contrary to that of the lower; the latter having the violet at A, and the red at B; but the former having the red at C, and the violet at D. Thoſe colours are blended into each other, ſo that no eye can diſtinguiſh their boundaries; and indeed for moſt eyes it is difficult to diſtinguiſh more than the three or four more predominant colours.

Sir Iſaac Newton calculated the breadth of each bow, as alſo the diſtance between them; but on the ſuppoſition that the light which comes from the ſun and forms the bows amongſt the drops of rain, came from a ſingle point, viz. from the centre of the ſun. The reſult of that calculation is, that at the eye of the obſerver, the breadth of the internal or lower bow ſhould ſubtend an angle of 1°, 45′, the breadth of the external, which is much broader, ſhould ſubtend an angle of 3°, 10′; and that the diſtance between the two bows ſhould ſubtend an angle of 8°, 55′. But as the ſun is not a point, and as the light proceeds from every part of its ſurface, the diameter of which ſubtends an angle of about half a degree; therefore the breadths of the bows are larger, and the diſtance between them is leſs than the above-mentioned reſults. Actual meaſurement with a quadrant, when the colours are vivid, conſtantly ſhews that the breadth of the lower bow ſubtends an angle of 2°, 15′; the breadth of the upper bow ſubtends an angle of 3°, 40′, and the diſtance between both bows ſubtends an angle of 8°, 25′. Alſo the ſemidiameter of the circle, of which the external part of the lower bow is an arch, ſubtends an angle of 42°, 17′; and the ſemidiameter of the circle, of which the internal part of the upper bow is an arch, ſubtends an angle of 50°, 42′.

The ſituation of the rainbows changes according as the eye of the ſpectator changes ſituation; for otherwiſe their breadths, &c. could not ſubtend conſtantly the ſame angles; hence no two perſons can ſee the ſame bow preciſely, or the ſame colour, in the very ſame place.

When the ſpectator is upon a plain, and the ſun is cloſe to the horizon, the rainbow is a ſemicircle; but, according as the ſun is higher above the horizon, ſo the rainbow is a ſmaller part of a circle. The inner or lower bow cannot appear when the elevation of the ſun exceeds 42°; and even the upper bow diſappears when the elevation of the ſun exceeds 54°.

When the ſpectator is upon an eminence, and the ſun is near the horizon, then the rainbow may exceed a ſemicircle; and if the elevation of the ſpectator be very great, and the rain near him, then the rainbow may form a complete circle: for in all caſes the centre of the bow, the ſpectator, and the ſun

ſun, muſt be in the ſame ſtraight line, which is called the *line of aſpect.*

The rainbow ſometimes is complete from one part of the ground to the other; and at other times it is interrupted, either in the middle or in ſome other part. This happens when the rain is partial; for it is in the drops of rain that the bows are formed, or that the light is diſperſed into its coloured rays. The interruption, however, may alſo be produced by the interpoſition of clouds, &c.

It follows likewiſe, from the various diſtances of the rain, and from the wind, which impels the rain obliquely, that ſometimes the rainbow appears inclined, or even of an oval form.

The uſual way of accounting for the formation of the rainbow, or for the diſperſion of white light into colours, amongſt the drops of rain, is as follows:

Let *s t* D, fig. 11, Plate XXII. repreſent a drop of water in the ſky. S *s* is a beam of the ſun's light that falls upon it. This ray, on account of the refractive power of water, will not proceed ſtraight towards F, but will be bent towards the perpendicular *s* C, ſo as to impinge upon the ſurface of the drop at *t*. At that place part of the light paſſes through the drop into the air; but another part of it is reflected, making the angle of reflection equal to that of incidence, and in coming out of the water into the air at *e*, is refracted, viz. bent from the ſtraight direction *e f*, ſo as to make the angle *p e*O, with the perpendicular C *p*, larger than the angle C *e t* (ſee page 169.) In ſhort, the beam of light S *s*, by going in and out of the drop, ſuffers two refractions, viz. at *s* and *e*, and one reflection at *t*. By calculating the directions it muſt take at thoſe places, (according to the method deſcribed in page 190,) it will be found that the angle SFO is 42°. 2′.

By theſe refractions the light is diſperſed into the priſmatic colours O *e* B; the red light, as the leaſt refrangible, being next to *e* O, and the violet next to *e* B; therefore an eye ſituated at O will perceive a red light at *e*. If the eye be raiſed gradually higher, it will perceive the orange next, then the yellow, then the green, &c. and laſt of all will perceive the violet.

Now this would be the caſe if there were a ſingle drop of rain in the ſky, and that drop remained immoveable: but it is eaſy to conceive that if the eye of the ſpectator remain immoveable, and the drop deſcend gradually from C to E, then the eye will likewiſe perceive all the colours ſucceſſively, from the red to the violet; and ſince, in a ſhower of rain a vaſt number of drops are to be found at the ſame time between C and E; therefore the eye will at the ſame time receive the red light from the drops at C, or near it, the orange from drops that are a little lower, the yellow from thoſe that are lower ſtill, &c.; and, laſtly, the violet from the loweſt at at E. Hence the violet, which is ſeen in the direction O E, is the loweſt colour of the firſt rainbow; and the red, which is ſeen in the direction O *e*, is the higheſt.

Since the incident and the refracted ray muſt make a given angle, as S F O, in order to ſhew a certain colour; it follows, that the rainbow muſt be the arch of a circle, or rather the baſe of a cone, the axis of which (viz. the *line of aſpect)* paſſes through the eye of the ſpectator, and through the ſun, which forms the vertex of the cone; for in that caſe only ſtraight lines drawn from any point of the rainbow to the ſun, and to the eye of the obſerver, form the ſame requiſite angle. Hence we ſee why, when the line of aſpect is upon the horizon, the bow muſt be a ſemicircle; alſo, why it muſt be leſs than a ſemicircle, when the line of aſpect is inclined from the ſun downwards, &c.

Having ſpoken above of the incident ray, or beam of light S *s*, it may perhaps be neceſſary to obſerve, for the ſake of perſpicuity, that this is not the only light that falls from the ſun upon the drop *s t* D; for there are numberleſs rays that fall upon its whole ſurface; but as they fall with different inclinations, ſo all their emergent parts cannot come to the ſame eye: hence we have taken notice of that light only, which impinging upon the drop in the direction S *s*, can (after the two refractions at *s* and *e*, and a reflection at *t*,) come to the eye at O.

There

There is, however, another part of the light incident upon a drop of rain, which, after two refractions, and two reflections, can come to the ſame eye when placed at a proper diſtance; and this is the light which forms the ſecond or external rainbow.

Let *d*G*s* (fig. the ſame) be a drop of rain higher than the drop *st*D. Y*s* is a ray of light, which enters it at *s*, and inſtead of proceeding ſtraight towards *a*, is refracted towards the perpendicular *s*C; it is then partly reflected from *d* to *e*, and again from *e* to *g*; making both at *d*, and at *e*, the angles of reflection reſpectively equal to the angles of incidence. Laſtly, on going out of the drop at *g*, this ray is refracted from the perpendicular *q*C, and is diſperſed into the coloured ſector B*g*O, having the violet colour, which ſuffers the greateſt refraction, next to B*g*; and the red, which is the leaſt refrangible next to *g*O; ſo that the colours of the upper rainbow are in an order contrary to that of the lower rainbow. By calculating the changes of the direction which take place at the two places of refraction *s*, *g*, (ſee page 190,) and at the two places of reflection *d*, *e*, it will be found that the emergent red ray *g*O, makes with the incident ray Y*b*, an angle O*b*Y of 50°, 57′.

On account of the light ſuffering one reflection more, and continuing longer in the drop G*ds* than in the drop *st*D, the angle of diſperſion B*go* is larger than the angle of diſperſion O*e*B: hence the upper rainbow is broader than the lower; but its colours are not near ſo vivid as thoſe of the lower.

I need not repeat what has been ſaid above in explanation of the particulars relative to the form, extent, &c. of the lower rainbow; for the ſame explanation, with few obvious changes, is applicable to the upper rainbow.

A rainbow is alſo produced, and for the ſame reaſons, by the light of the moon; but (as it may naturally be expected) the colours of the lunar rainbow are not nearly ſo vivid as thoſe of the ſolar rainbow *.

Such a coloured bow is not unfrequently ſeen at ſea in the ſpray or drops of water, which the wind diſperſes or carries away from the tops of the waves. The colours of this bow are not ſo lively as thoſe of the common rainbow; the moſt vivid are a yellow next to the ſun, and a green next to the ſea. Thoſe bows, of which a great many are often to be ſeen at the ſame time, have a poſition contrary to that of the common rainbow; viz. the curve part is towards the ſea, and the legs upwards.

A coloured bow is always to be ſeen amongſt the ſcattered water of a jet, a broken caſcade, and the like, when the ſun and the ſpectator are in proper ſituations.

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* See the account of a remarkable lunar bow in the Philoſophical Tranſactions, N° 331.

Sometimes a coloured bow is cauſed by the refraction of the ſun's rays in the drops of dew upon the graſs. The convex part of ſuch bow is turned towards the ſpectator.

In ſhort, a coloured bow, larger or ſmaller, ſtronger or weaker, according to circumſtances, is always to be ſeen when drops of water, the ſun, and the ſpectator, are properly ſituated. A perſon may ſee it if he turns his back to the ſun, and forces ſome water violently, and in broken ſtreams, from his mouth. But the beſt way of imitating a rainbow is to faſten a number of ſmall ſolid glaſs balls, or a number of ſmall glaſs bubbles full of water, upon a dark board, and to preſent the board thus furniſhed to the ſun at a proper inclination, which experience eaſily finds, whilſt you turn your back to the ſun and look at the board.

Another ſort of luminous appearances under the name of *halos* or *coronas*, may be frequently obſerved in the ſky. Theſe are circular zones of pale light, moſtly white, but ſometimes variouſly coloured, which are ſeen round the ſun, the moon, and even round ſome very bright ſtar or planet. The halo is ſometimes quite cloſe to the luminous body. "Thoſe which have been ſeen about Sirius
" and Jupiter were never more than 3, 4, or 5 de-
" grees in diameter; thoſe which ſurround the
" moon are, alſo, ſometimes no more than 3 or 5
" degrees. But theſe, as well as thoſe which ſur-
" round the ſun, are of very different magnitudes,

" viz. from 12°, to 90°, or even larger than this. " Their diameters alſo ſometimes vary during the " time of obſervation; and the breadths both of the " coloured and white circles are very different, viz. " of 2, 4, or 7 degrees.

" The colours of theſe coronas are more dilute " than thoſe of the rainbow; and they are in a dif" ferent order, according to their ſize*."

Coronas may be produced by placing a lighted candle in the midſt of ſteam in cold weather.

Various opinions have been entertained by different philoſophers concerning the real cauſes of ſuch halos or coronas. But whether they are owing to the refraction, or the reflection, or the inflection, of light, or to all thoſe cauſes, and in what propor-

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* " In thoſe which Newton obſerved in 1692, they were " in the following order, reckoning from the inſide. In " the innermoſt were blue, white, and red; in the middle " were purple, blue, green, yellow, and pale red; in the " outermoſt, pale blue, and pale red. M. Huygens obſerved " red next the ſun, and a pale blue outwards. Sometimes " they are red on the inſide, and white on the outſide. Mr. " Weidler obſerved one that was yellow on the inſide, and " white on the outſide. In France one was obſerved in " 1683, the middle of which was white; after which fol" lowed a border of red, next to it was blue, then green, " and the outermoſt circle was a bright red. In 1728 one " was ſeen of a pale red outwardly, then followed yellow, " and then green, terminated by white." Prieſtley's Hiſt. of Viſion, Light, and Colours, P. VI. Sect. XI.

tion, is not yet ſatisfactorily determined [*]. It appears, however, that they are formed in ſuch aggregations of vapours as are not heavy enough to fall in the form of drops [†].

A more remarkable, but much leſs frequent, ſpecies of phenomena are ſometimes ſeen in the heavens; they are called *parhelia* and *paraſelenes*, vulgarly called *mock-ſuns* and *mock-moons*. They ſeem to be reflections of the ſun and of the moon from zones of denſe vapours that happen to be collected in the ſky.

Parhelia have been ſeen and are mentioned by various authors [‡].

"The apparent ſize of parhelia is the ſame as "that of the true ſun; but they are not always "round, and alſo, they are not always, though "they are ſometimes ſaid to be, as bright as "the true ſun. When there are numbers of

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[*] The various opinions are collected by Dr. Prieſtley in the above-mentioned Section of his Hiſtory, &c. See alſo an anonymous publication, entitled, *An Account of Irides or Coronæ.* London 1799.

[†] Deſcartes remarks, that halos never appear when it rains. Dioptrics, page 230.

[‡] Ariſtotle, Pliny, Gaſſendi, De la Hire, Caſſini, Deſcartes, Newton, Mr. Grey, Dr. Halley, &c. but a conciſe account of all their obſervations, as alſo of the opinions which have been entertained concerning the formation of ſuch phenomena, may be ſeen in Dr. Prieſtley's Hiſtory of Viſion, Light, and Colours, P. VI. Sect. XI. from which the above account is taken.

"them,

"of them, ſome are not ſo bright as others. Ex-
"ternally they are tinged with colours, like the
"rainbow, and many have a long fiery tail oppo-
"ſite to the ſun, but paler towards the extremity.
"Dr. Halley obſerved one which had tails extend-
"ing both ways, and ſuch a one alſo M. Muſchen-
"broeck obſerved in 1753, the tails being in a
"right line drawn through both the ſuns. Both
"of them, alſo, were in coloured circles. M.
"Weilder ſaw a parhelion with one tail pointing
"upwards and another downwards, a little crook-
"ed; the external limb, with reſpect to the ſun,
"being of a purple colour, and on the other ſide it
"was tinged with the colours of the rainbow. The
"tails of theſe parhelia, for the moſt part, appear
"in a white horizontal circle.

"Coronas generally accompany parhelia, ſome
"tinged with the colours of the rainbow, and
"others white. They differ in number and ſize,
"but they are all of the ſame breadth, which is
"that of the apparent diameter of the ſun.

"A very large *white circle*, parallel to the ho-
"rizon, generally paſſes through all the parhelia;
"and if it were entire, it would go through the
"centre of the ſun. Sometimes there are arcs of
"leſſer circles concentric to this, touching thoſe
"coloured circles which ſurround the ſun. They
"are alſo tinged with colours, and contain other
"parhelia."

Of the *aurora borealis*, or *northern light*, we ſhall make

make mention in the next ſection, under the title of Electricity: but we ſhall juſt obſerve in this place, that ſometimes, though by no means frequently, a pale white light more or leſs extended, is ſeen in the ſky, the cauſe of which is not known. It differs from the northern light principally by its being ſteady and uniform, whereas the northern light is lambent and changeable. The former is likewiſe more denſe than the latter; for it generally eclipſes the ſtars over which it paſſes. A remarkable appearance of this ſort was obſerved in London on the night of March the 27th, 1781 *.

The *zodiacal light* is a ſort of pyramidal whiteneſs, which is ſometimes ſeen above the horizon after the ſetting of the ſun, or before its riſing. Its whiteneſs is not much unlike that of the *via lactea*, or *milky way*. Its baſe is towards the ſun, and its extenſion is in the plain of the zodiac. Caſſini ſeems to have firſt taken notice of it in 1683. In the torrid zone the zodiacal light is frequently, or almoſt conſtantly ſeen. At or near our latitude it may be ſeen about the time of the equinoxes. The breadth of this whiteneſs is various; at the horizon it varies from 8 to 30 degrees; its extenſion, reckoning from the ſun to the apex of the light, generally exceeds 45°. Mr. Pingre, being in the torrid zone, ſaw it of 120 degrees.

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* Philoſophical Tranſactions, vol. 71, Art. XVI.

" At preſent, *ſays de la Lande*, it ſeems to be " generally believed, that the zodiacal light is the " atmoſphere of the ſun; for it always accompanies " that luminary, and the equator of the ſun is in " the direction of the zodiacal light. Therefore in " all probability the zodiacal light is an atmoſphere " ſituated round the ſun in the direction of its equa-" tor, and flattened by its rotatory motion*."

Various accounts of peculiar luminous appearances that are ſeen in particular places, and which are evidently owing to certain peculiar diſpoſitions of mountains, houſes, rivers, and other objects, are to be met with in different books; but none of theſe ſeems to be more remarkable, and leſs underſtood with reſpect to its cauſe, than the famous *Fata Morgana*, or apparition ſo called, which is frequently ſeen near the city of Reggio, ſituated towards the extremity of the kingdom of Naples, and facing the iſland of Sicily.

" When the riſing ſun ſhines from that point, " whence its incident ray forms an angle of about " 45 degrees on the ſea of Reggio, and the bright " ſurface of the water in the bay is not diſturbed " either by the wind or the current, the ſpectator " being placed on an eminence of the city, with his " back to the ſun and his face to the ſea;—on a " ſudden there appear in the water, as in a catop-" tric theatre, various multiplied objects, viz. num-

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[*] Aſtronom. Paris 1771, § 845 to 849.

"berleſs ſeries of pilaſters, arches, caſtles well delineated, regular columns, lofty towers, ſuperb palaces, with balconies and windows, extended alleys of trees, delightful plains with herds and flocks, armies of men on foot and horſeback, and many other ſtrange images, in their natural colours and proper actions, paſſing rapidly in ſucceſſion along the ſurface of the ſea during the whole of the ſhort period of time while the abovementioned cauſes remain.

"But if, in addition to the circumſtances before deſcribed, the atmoſphere be highly impregnated with vapour, and denſe exhalations not previouſly diſperſed by the action of the wind or waves, or rarefied by the ſun, it then happens that in this vapour, as in a curtain extended along the channel to the height of about 30 palms, and nearly down to the ſea, the obſerver will behold the ſcene of the ſame objects not only reflected from the ſurface of the ſea, but likewiſe in the air, though not ſo diſtinct or well defined as the former objects from the ſea.

"Laſtly, if the air be ſlightly hazy and opake, and at the ſame time dewy and adapted to form the iris, then the above-mentioned objects will appear only at the ſurface of the ſea, as in the firſt caſe, but all vividly coloured or fringed with red, green, blue, and other priſmatic colours[*]."

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[*] *Diſſertazione prima ſopra un Fenomeno volgarmente detto Fata Morgana. Del P. Antonio Minaſi. Roma* 1773.

This phenomenon is related with ſome variety of circumſtances, and has been differently explained, by various writers. Upon the whole, it ſeems that the appearances of houſes, trees, &c. are only the reflections of the objects of the city of Reggio, and of the coaſt. They ſeem to be reflected from the ſurface of the ſea, and from the ſurface of denſe vapours or clouds in the air cloſe to the ſea; and according to the various forms and number of the reflecting ſurfaces, thoſe objects are multiplied, magnified, inverted, elongated, or otherwiſe diſtorted. But the exact explanation of the phenomenon muſt be left for the ingenuity of future obſervers.

I ſhall cloſe this chapter with a conciſe account of phoſphoreſcent bodies, among which I ſhall reckon the *ignis fatuus*, or *jack-a-lantern*.

The name of phoſphorus has of late been given to a particular primitive ſubſtance, of which ſufficient mention has been made in the ſecond volume of theſe Elements; but in its more extenſive application, that name means every ſubſtance that ſhines in the dark, without the production of ſenſible heat.

The phoſphoreſcent bodies may be divided into five ſpecies, viz. I. The living animals which have the property of ſhining in the dark, ſuch as glow-worms, lantern flies, of which there ſeems to be ſeveral ſpecies, but of the mechaniſm which produces their light, nothing certain is known. In this country ſome

ſome of them, in their beſt ſtate, afford light barely enough to read the hour on a watch that has a clear dial. In warmer climates their light is much more powerful. The light of thoſe inſects generally ceaſes after death; but whilſt living they may either ſhow it or not at pleaſure.

II. Thoſe bodies which abſorb light, and then yield it in the dark.

A vaſt number of ſubſtances have the property of ſhining for a certain time in the dark, after having been previouſly expoſed to light; but they have it in different degrees of intenſity as well as of duration. Several precious ſtones, and calcareous bodies, eſpecially after calcination, have this property, as alſo paper, and almoſt all vegetable and animal ſubſtances when very dry, or after ſolution in nitrous acid. Metallic ſubſtances and water have not this property; yet congealed water, viz. ice, and eſpecially ſnow, have it in a conſiderable degree [*].

There is a mineral, called the *Bolognian ſtone*, which, after due preparation, has this property in a very remarkable degree [†]. Thoſe ſtones are moſtly found

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[*] Beccari's Experiments in the Comment. Bonon. vol. V. page 106.

[†] The proper or effectual method of preparing this ſtone ſeems to be kept ſecret. Several trials made in this country have ſucceeded but partially. Kircher directs to reduce the ſtone

found in the neighbourhood of Bologna. This is an heavy grey ſpar of the barytic genus, properly called *baroſelenite*, and, from its weight, *marmor metallicum.*

If this ſtone, after due preparation, be expoſed to the day light, and then be brought into a dark room, it will be found to ſhine with a darkiſh red light, or to appear like ignited coals. This ſhining continues a few minutes, gradually decaying, and laſtly vaniſhing. By expoſing it again to the day light for a few ſeconds, its ſhining property is renewed as often as one pleaſes. It will become luminous even by expoſing it to candle light.

The reſiduum of the diſtillation of chalk and nitrous acid has the ſhining property, ſimilar to that of the bolognian ſtone, though not in ſo great a degree. This is called (from its inventor) *Baldwin's phoſphorus.*

Several other preparations have the property of abſorbing light, and then of yielding it in the dark; but none has it in ſo eminent a degree as that

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ſtone into a fine powder, together with white of egg, water or linſeed oil. The paſte thus formed muſt be put in a furnace, and muſt be calcined to a certain degree. Others direct to place the bolognian ſtone amongſt lighted charcoal, and to leave it undiſturbed therein until the coals are conſumed. Other methods have alſo been deſcribed; but, not knowing which of them is the beſt, I ſhall not trouble the reader with any more of them.

which was diſcovered by the late Mr. Canton, and which is prepared in the following manner:

"Calcine ſome common oyſter-ſhells," (if they be old, and half calcined by time, ſuch as are found upon the ſea-ſhore, they are ſo much the better) "by keeping them in a good coal-fire for half an "hour; let the pureſt part of the calx be pulve-"rized and ſifted; mix with three parts of this "powder one part of the flowers of ſulphur; let "this mixture be rammed into a crucible of about "an inch and a half in depth, till it be almoſt full; "and let it be placed in the middle of the fire, "where it muſt be kept red hot for one hour at "leaſt, and then ſet it by to cool; when cold, turn "it out of the crucible, and cutting or breaking it "to pieces, ſcrape off, upon trial, the brighteſt part, "which, if good phoſphorus, will be a white pow-"der, and may be preſerved by keeping it in a dry "phial with a ground ſtopple*."

If this phoſphorus, whether in the phial or not, be kept in the dark, it will give no light, but if it be expoſed to the light, either of the day, or of any other body ſufficiently luminous, and afterwards be brought into a dark place, it will appear luminous for a conſiderable time, viz. a few minutes. Its light is white with a ſhade of blue or green.

A little of this phoſphorus, when firſt brought into a dark room, after having been expoſed for a

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* Philoſophical Tranſactions, vol. 58, page 337.

few ſeconds on the outſide of a window to the common day light, will give light enough to diſcover the hour on a watch; provided the eyes of the obſerver have been ſhut or in the dark two or three minutes before.

It has been long queſtioned whether thoſe phoſphori ſhine by yielding the light which they have firſt imbibed, or by yielding their own light, kindled as it were by the action of foreign light; and though the former opinion be by far the moſt probable, yet the queſtion is not quite ſatisfactorily determined.

In order to elucidate this point, various ingenious perſons have attempted to illumine thoſe phoſphori by coloured light, as for inſtance, by red, or green, or blue, or yellow light; but their reſults do not agree. Algarotti having illuminated the bolognian phoſphorus, by differently coloured light produced by a priſm, found that the phoſphorus was faintly illuminated by this means, but he could not diſtinguiſh any difference of colour in it *.

Beccaria of Turin obſerved, that pieces of artificial phoſphorus, much ſuperior to the bolognian, incloſed in tubes into which the light was admitted through pieces of coloured glaſs, exhibit that particular colour only; yet this effect has been denied by ſubſequent obſervers.

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* Acad. Par. 1730.

The determination of this queſtion would go a great way towards proving that light is real matter emanated by the luminous body, rather than a modification of a fluid univerſally diſperſed. But independent of this queſtion, what principally ſeems to prove the materiality of light, is the change which light alone produces on various bodies, viz. on vegetables, on ſolutions of ſilver, &c. *

III. The bodies which produce light when heated, form the third ſpecies of phoſphory. The beſt method of heating bodies in a dark room for this purpoſe, " is to reduce the body to a " moderately fine powder, and to ſprinkle it, by " ſmall portions at a time, on a thick plate of iron, " or maſs of burnt luting made of ſand and clay, " heated juſt below viſible redneſs, and removed " into a perfectly dark place." †

A great variety of ſubſtances ſhine when they are ſo treated, viz. fluoric ſtones, ſeveral marbles, diamond and other precious ſtones, calcareous earth, metallic ſubſtances, ſea coal, oils, wax, butter, paper, and ſeveral other animal and vegetable ſubſtances.

" The duration, *ſays Mr. Wedgwood* ‡, of the " light thus produced from different bodies is very

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[*] See Count Rumford's Paper in the Philoſophical Tranſactions, Volume for the year 1798, Art. XX.

[†] See Mr. T. Wedgwood's Paper in the Philoſophical Tranſactions, Volume for the year 1792, Art. III.

[‡] Ibid.

"unequal; in ſome the light is almoſt momentary, "in others it laſts for ſome minutes, and may be "prolonged by ſtirring the powder on the heater. "It ſoon attains its greateſt brightneſs, and dies "away gradually from that point, never appearing "in a ſudden flaſh, like the light of quartz pebbles "rubbed together. If blown upon, it is ſuddenly "extinguiſhed, but immediately reappears on diſcontinuing the blaſt."

The light of the preceding ſpecies of phoſphori is alſo expelled more effectually by heat; but when the quantity of light previouſly imbibed has been once yielded, then they will ceaſe to ſhine unleſs they be expoſed again to the light; whereas the phoſphori of this third ſpecies give out light and heat, without the neceſſity of having been previouſly expoſed to external light. It muſt be obſerved, however, that ſeveral bodies are phoſphori of both ſpecies.

IV. Several ſubſtances yield a light either quite white, or with different ſhades of red, or blue, by attrition, viz. when they are rubbed or knocked one againſt the other. The light is generally ſpread beyond the touching parts, and ſometimes it ſpreads all over the bodies.

Almoſt all the ſtones of the ſiliceous genus, ſuch as quartz, flints, agates, &c. have this property, as alſo glaſs, porcelain, hard baked earthenware, &c.

This light is often accompanied with a faint but peculiar ſmell. Some of thoſe bodies during attrition,

tion, emit now and then reddiſh ſparks of a vivid light, which retain their brightneſs in a paſſage of 1, 2, and even 3 inches through the air.

V. The phoſphori of this laſt ſpecies are thoſe which emit light whilſt they are in an evident ſtate of decompoſition. Of this ſort are moſt animal matters, and ſome vegetable ſubſtances, eſpecially rotten wood. In ſome of them the light ſeems to belong to the extrication of phoſphorus properly ſo called; whilſt in others a pure light ſeems to be produced. Upon the whole it appears, that light enters into combination with various bodies, and forms one of their conſtituent principles, eſpecially with animal and vegetable ſubſtances; and that when thoſe ſubſtances are in a ſtate of decompoſition, the light being one of the ingredients, is ſeparated from the reſt, &c. It alſo ſeems that the light is ſeparated either very ſlowly, in which caſe it is not perceived; or quickly, when it becomes viſible. In ſome bodies it is the firſt produce of the decompoſition, viz. before any putrid effluvium is perceived; in others, it is yielded at different periods.

Of all the animals, fiſh ſeems to afford the greateſt quantity of light, and they yield it in the greateſt quantity before the putridity takes place. Almoſt every body is acquainted with the ſhining property of fiſh; but the moſt recent and entertaining experiments upon this ſpecies of animals, and particularly with the herring and the mackerel, were made

made by Dr. Hulme, and are deſcribed in the Philoſophical Tranſactions for the year 1800, Article IX. from which the following particulars have been extracted.

Herrings and mackerels (and probably moſt other fiſhes) begin to appear luminous about the ſecond day after their having been taken out of the water. The light increaſes whilſt they are perfectly good and ſweet; but it begins to decreaſe when the fiſh begins to putrefy, and it decreaſes according as the putreſcence increaſes.

It is not the external ſurface only of thoſe animals that is capable of ſhining; but the light ſeems to be incorporated with their whole ſubſtance, and to make a part thereof, in the ſame manner as any other conſtituent principle; for if the fiſh be cut in various pieces, the whole ſurface of every piece becomes luminous, if kept in a dark and rather cool place; eſpecially the ſoft roe both of the herring and of the mackerel, which look like a complete body of light at about the third or fourth night, which generally is the period of their greateſt brightneſs.

Hence it ſeems that the decompoſition of the fiſh begins very ſoon, but the light is the firſt principle that eſcapes, and which takes place long before any fœtid or putrid effluvium can be perceived.

This light is not accompanied with any degree of heat that may be diſcovered by the thermometer.

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The luminous matter of fiſhes, or the thickiſh liquor with which this light is incorporated, may be ſcraped off by means of a knife from over their ſurfaces, and may be preſerved in a phial, where it will continue to ſhine for a day or two, or longer, according to circumſtances. But there are ſome ſubſtances which, being mixed with this luminous matter in a certain proportion, will extinguiſh its light; and it is very remarkable that ſome of thoſe very ſubſtances, but mixed in another proportion, will increaſe or preſerve it for ſome time longer.

" Thoſe which extinguiſh it are, water alone; water impregnated with quicklime; water impregnated with carbonic acid gas; water impregnated with hepatic gas; fermented liquors; ardent ſpirits; mineral acids, both in a concentrated and in a diluted ſtate; vegetable acids; fixed and volatile alkalies, when diſſolved in water; neutral ſalts, viz. *ſaturated* ſolutions of Epſom ſalt, common ſalt, and of ſal ammoniac; infuſions of chamomile flowers, of long pepper, and of camphor, made with boiling-hot water, but not uſed till quite cold; pure honey, if uſed alone."

On the other hand, a very moderate ſolution of ſome of the above-mentioned ſubſtances, as for inſtance, about a dram of Epſom ſalt, or of Glauber's ſalt, or of Rochelle ſalt, or of phoſphorated ſoda, or of nitre, or of common ſalt, or of honey, or of ſugar, diſſolved in an ounce of water, and then mixed with the luminous matter of fiſhes, will render their light ſtronger and more durable.

"Two ounces of ſea water, being agitated with "the light of mackerel, ſoon obtained a brilliant "illumination. The ſea water preſerved its lumi-"nouſneſs for ſeveral days."

Any of the laſt-mentioned ſolutions, being impregnated with the luminous matter, and left ſome time at reſt, are rendered more lucid by a moderate degree of heat; but an higher degree of heat, ſuch as that of about boiling water, extinguiſhes them totally and permanently.

Cold extinguiſhes this light in a temporary manner; for the light is revived in its full ſplendour as ſoon as it is expoſed to a moderate degree of heat.

The light of thoſe mixtures is rendered more vivid by motion, viz. by agitating the phial which contains the liquor, or by drawing ſome hard body through it. This ſeems fully to explain the cauſe of that phoſphoreſcent light which at night is ſeen on the ſurface of the ſea, when the water is agitated by a high wind, or by the daſhing of oars, &c.

When this luminous matter of fiſhes is extinguiſhed by being mixed with ſome of the ſaturated ſolutions of the above-mentioned kind, its light is not totally loſt, but it may be revived in its former ſplendour by converting the ſolution into one of the latter ſort; for inſtance, if the light be extinguiſhed by the admixture of a ſaturated ſolution of ſalt, add more water to the mixture, ſo as to diminiſh the proportion of ſalt, and the light is thereby revived; and on the contrary, if to the latter more ſalt be added, the light will be extinguiſhed, and ſo on.

" Some ſhining matter, *ſays Dr. Hulme*, was " taken from a mackerel, and mixed with a ſolu- " tion of ſeven drams of Epſom ſalt in one ounce " of water; and its light was immediately extin- " guiſhed. The ſame effect enſued, but in a leſs " degree, with a ſolution of ſix and of five drams. " In a ſolution of two drams, in the ſame quantity " of water, the liquid was luminous; but much " more ſo when only one dram of ſalt was uſed. " Obſerving the extinction of light to take place, " as above, in the more ſaturated ſolutions, while " the diluted ſolutions were luminous, it occured " to me to endeavour to diſcover what became of " the extinguiſhed light, in the former caſe, and " whether it might not be revived by dilution. " For this purpoſe I took the ſolution of ſeven " drams of ſalt in one ounce of water, in which " the lucid matter from a mackerel had been ex- " tinguiſhed, and diluted it with ſix ounces of cold " pump water; when, to my great aſtoniſhment, " light in a moment burſt out of darkneſs, and the " whole liquid became beautifully luminous! This " revived light remained above 48 hours, that is,

" as long as other light in general does, which has " never been extinguiſhed. Hence, it had loſt " nothing of its vivid luminous powers by its ex- " tinction."

The fleſh of quadrupeds ſometimes has alſo been obſerved to emit light *. Light has alſo ſometimes been ſeen on burying grounds, which is attributed to the ſame cauſe, viz. to the decompoſition of animal matter.

Vegetable ſubſtances in a ſtate of decompoſition, and eſpecially rotten wood, are ſometimes ſeen to ſhine in the dark; but amongſt the various luminous appearances which ſeem to owe their origin to a decompoſition of animal and vegetable matter, none is ſo famous, and yet ſo imperfectly known as the *ignis fatuus*, or *jack-a-lantern*, which has been variouſly related by ignorance, apprehenſion, and exaggeration.

It has been the opinion of certain philoſophers that the *ignis fatuus* is produced by ſhining inſects. Sir Iſaac Newton called it *a vapour ſhining without heat*; and this ſeems to be the moſt probable opinion, eſpecially if it be allowed to owe its origin to the decompoſition of animal and vegetable ſubſtances.

Waving however any farther conjecture, I ſhall juſt add two of the moſt authentic accounts of ſuch appearances that I find recorded.

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* See T. Bartholin *de luce animalium*, p. 183. Boyle's Works, vol. III. p. 304. Phil. Tranſ. vol. XI. p. 599.

It is related by Dr. Derham, that, having obſerved an *ignis fatuus* in ſome boggy ground, between two rocky hills, in a dark and calm night, he got by degrees within two or three yards of it, and thereby had an opportunity of viewing it to the greateſt advantage. It kept ſkipping about a dead thiſtle, till a ſlight motion of the air, occaſioned, as he ſuppoſed, by his near approach to it, made it jump to another place; and as he advanced, it kept flying before him. He was ſo near to it, that, had it been the ſhining of glow-worms, he was ſatisfied that he could not but have diſtinguiſhed the ſeparate lights of which it muſt have conſiſted; whereas it was one uniform body of light. He therefore thought that it muſt be an ignited vapour *.

Mr. Beecari made particular inquiry concerning the *ignis fatuus*. He found that two, which appeared on the plains, one to the north and the other to the eaſt of Bologna, were to be ſeen almoſt every dark night, eſpecially the latter; and the light they gave was equal to that of an ordinary faggot. That to the eaſt of Bologna once appeared to a gentleman of his acquaintance, as he was travelling, and kept him company above a mile, conſtantly moving before him, and caſting a ſtronger light upon the road than the torch, which was carried along with him. All theſe luminous appearances, he ſays, gave light enough to make all neighbouring objects viſible,

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* Prieſtley's Hiſtory of Viſion, Light, &c. p. 580.

and they were always obſerved to be in motion, but this motion was various and uncertain. Sometimes they would riſe up, and at other times ſink; but they commonly kept hovering about ſix feet from the ground. They would alſo diſappear of a ſudden, and inſtantly appear again in ſome other place. They differed both in ſize and figure, ſometimes ſpreading pretty wide, and then again contracting themſelves; ſometimes breaking into two, and then joining again; ſometimes floating like waves, and dropping, as it were, ſparks of fire. He was aſſured that there was not a dark night all the year round in which they did not appear, and that they were obſerved more frequently when the ground was covered with ſnow than in the hotteſt ſummer; nor did rain or ſnow in the leaſt hinder their appearance; but, on the contrary, they were obſerved more frequently, and caſt a ſtronger light in rainy and wet weather; nor were they much affected by the wind *.

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* Prieſtley's Hiſtory of Viſion, &c. p. 581. Phil. Tranſ. vol. 36, p. 204.

SECTION III.

ON ELECTRICITY.

THE moſt enlightened and inquiſitive perſons of the third or fourth century before the Chriſtian æra, were acquainted with a remarkable property of, at leaſt, two mineral bodies, one of which was *amber*, and the other was a hard ſtone, called *lyncurium* by Theophraſtus (probably the ſame as is at preſent known under the name of *tourmalin.)* They knew that either of thoſe bodies, and in particular the former, after a ſlight friction, would attract any kind of ſmall bodies, ſuch as bits of ſtraw, aſhes, &c. that might be preſented to it within a certain diſtance.

They knew likewiſe that another mineral, which they called *magnet*, would attract iron, and all ſuch bodies as contained a ſufficient quantity of that metal. But a wide difference obviouſly exiſted between the power of the magnet, and that of the other above-mentioned bodies. The magnet attracted iron only, and its attractive property required no previous friction; the other bodies could not act without previous friction, but then they would attract bodies of every kind indiſcriminately, provided they were ſufficiently light.

In proceſs of time it was found that ſeveral other bodies, ſuch as precious ſtones, ſulphur, glaſs, &c. poſſeſſed preciſely the ſame attractive property, not as the magnet, but as the amber; therefore they were ſaid to have the property of the amber, which, in the Greek language, was called ηλεκτρον, whence the word *electricity* has been derived, and hence thoſe bodies were ſaid to be poſſeſſed of *electricity*, or of the *electric* property. After the lapſe of ſome centuries it was found that larger bodies, moderately warm, dry, and properly rubbed, would attract from a greater diſtance, and with greater force, than ſmaller bodies of the ſame ſort; and as it was eaſy to procure large pieces of glaſs and ſulphur, attempts to increaſe the attractive property of thoſe ſubſtances were ſoon made, and thoſe attempts gradually diſcloſed ſeveral other properties of the ſame electric power.

It was diſcovered that the ſame body would not only attract, but alſo repel, the light bodies; the attraction and repulſion ſucceeding each other repeatedly.

It was diſcovered that this attractive property might be communicated from the glaſs or ſulphur, or amber, &c. to other bodies, which could not of themſelves acquire it by rubbing.

It was obſerved that on touching the body which had

had been rubbed (otherwiſe ſaid to be excited, or to be electrified), luminous ſparks were ſeen to proceed from it, and thoſe ſparks were accompanied with ſnappings, viz. an audible noiſe; and when any part of the ſurface of the animal body was preſented to the electrified ſubſtance, a ſenſation was perceived, as if ſomething ſtruck the part at the time that the ſpark was manifeſted.

Thoſe diſcoveries were moſtly made in the 17th century, and being incomparably more ſurprizing than the mere attraction of a bit of amber, they produced an aſtoniſhing degree of curioſity, of induſtry, and of emulation amongſt the philoſophers of Europe. The multiplicity of labourers, the variety of machines that were contrived, and of experiments that were inſtituted, produced farther diſcoveries ſtill more ſurpriſing than the preceding, and rendered the ſubject of electricity highly intereſting in the eye of the philoſopher.

It was diſcovered that the electric power could be accumulated in what is called the *Leyden phial*, ſo that inſtead of a ſingle ſpark from a piece of excited ſulphur or of excited glaſs, the force of ſeveral ſuch ſparks could be collected in that phial, and could afterwards be diſcharged all at once upon any given body, upon which it would produce very extraordinary effects. In ſhort, ſuch diſcharge will inſtantly melt even the moſt refractory metallic bodies, it kills animals, fires combuſtible bodies, breaks

breaks ſolids, &c. in exact imitation of thoſe effects which have been long known to be produced by lightning.

Indeed, not long after the diſcovery of the Leyden phial, the identity of electricity and the power which produces the thunder and lightning, was fully and ſatisfactorily proved.

Subſequent to this it was diſcovered that electricity is excited by a variety of other means beſides friction, ſuch as by heating, cooling, evaporation, condenſation, effervеſcence, &c.; or rather it appears that there is hardly an operation of nature in which the electric power is not concerned. But whilſt we admire the univerſality of its influence, whilſt we applaud the ingenuity of philoſophers for having acquired the knowledge of ſo many wonderful facts, we muſt confeſs our utter ignorance of the cauſe which produces them; and thus we are at once forced to acknowledge the ſtrength and the weakneſs of the human underſtanding.

The very extenſive influence of electricity throughout the operations of nature, its great power, and its conſtant action, ſeem to indicate that it muſt be eſſentially concerned in various grand and neceſſary proceſſes. Yet in the inveſtigation of its nature, of its influence, and of its uſe, we have had only ſuppoſitions for guide, and we have nothing but hypotheſes, viz. ſuppoſitions, to offer.

The ſtatement of thoſe facts, the moſt uſeful application of the ſame, and the beſt hypotheſes which have been offered for their explanation, will form the materials of the preſent ſection *.

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* See Dr. Prieſtley's Hiſtory and preſent State of Electricity.

CHAPTER I.

CONTAINING A GENERAL IDEA OF ELECTRICITY.

IF a perſon, holding with one of his hands a clean and dry glaſs tube, rubs it with his other hand, which muſt alſo be clean and dry, by ſtroking it alternately upwards and downwards; and after a few ſtrokes preſents to it ſmall light bits of paper, thread, metal, or of any other ſubſtance, the rubbed tube will immediately attract them, and after a ſhort time will repel them. It will preſently attract them again, then repel them, and ſo on; continuing this alternate attraction and repulſion for a conſiderable time.

If the glaſs tube be rubbed in the dark, and after having been ſtroked a few times, a finger be preſented to it at the diſtance of about half an inch, a lucid ſpark will be ſeen between the finger and the tube, and this ſpark is accompanied with a ſnapping noiſe; the finger at the ſame time receiving a puſh, as if it were from air iſſuing with violence out of a ſmall pipe *.

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* The other modes of exciting Electricity will be deſcribed hereafter.

In this experiment, the attraction, repulſion, ſparkling, &c. are the effects of that unknown cauſe, which is called *Electricity*; and hence they are called *electrical appearances.* The glaſs tube itſelf is called the *electric*, and all thoſe bodies which are capable of producing ſuch effects after friction, are called *electrics*; and as the rubbing awakes, as it were, in them the power of producing ſuch effects, they are therefore ſaid to be *excited* by the rubbing. The hand, or any other body that rubs an electric, is called the *rubber*; and if, inſtead of the perſon rubbing the glaſs tube, a machine be contrived capable of exciting an electric, that mechaniſm is called an *electrical machine.*

Let an oblong piece of metal, ſuch as a poker, a long metallic ſpoon, &c. be ſuſpended in the air by means of a dry *ſilk* ſtring, upwards of a foot long, from any convenient ſupport, as in fig. 1, Plate XXIII. and let ſmall light bodies, ſuch as have been mentioned in the preceding experiment, be preſented to its lower extremity, within about an inch of it; then having rubbed the dry glaſs tube as before, place it near the upper end A of the ſuſpended metallic body, and you will find that the lower end B of that body will attract and repel the light bodies, alſo will give ſparks, &c. exactly like the excited tube itſelf; which ſhews that the electric virtue paſſes through the metal from one end A to the other end B.

If, inſtead of the metallic body A B, you ſuſpend in in a ſimilar manner a glaſs ſtick, or a long ſtick of ſealing wax, and repeat the laſt deſcribed experiment, you will find that the lower part of the ſuſpended ſtick of glaſs or of ſealing wax, will not attract the light bodies, nor will it give any ſparks; which ſhews that the electric virtue will not paſs through glaſs or through ſealing-wax.

Now the above-mentioned metallic body, and all thoſe bodies through which the electric virtue can paſs, are called *conductors* of electricity. But the glaſs ſtick, the ſealing-wax, and all thoſe bodies through which the electric virtue cannot paſs, are called *non-conductors*. A body reſting entirely upon, or ſuſpended by, non-conductors, is ſaid to be *inſulated*.

All the bodies we are acquainted with, may be divided into conductors and non-conductors of electricity; and as it has been found that the non-conductors may be excited by friction, whereas the conductors cannot be excited by friction; therefore *electrics* and *non-conductors* mean the ſame bodies*; and *conductors* have alſo been called *non-electrics*.

Such is the outline or the general idea of thoſe principles of electricity; but thoſe diſtinctions are far

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* Electrics have alſo been called *electrics per ſe*. It muſt be obſerved, however, that certain ſubſtances, ſuch as oils, certain powders, &c. which are non-conductors, are called electrics from analogy; for they cannot be ſubmitted to friction.

from being accurately ſettled and determinate. For inſtance, we are not acquainted with any body which, ſtrictly ſpeaking, may be ſaid to be a perfect electric or a perfect conductor; the electric virtue finding ſome reſiſtance in going through the beſt conductors, and being partly tranſmitted through, or over the ſurface of, moſt, if not all the electrics. The leſs perfect conductor any ſubſtance is, the nearer it comes to the nature of an electric; and, on the other hand, the leſs perfect electrics come neareſt to the nature of conductors. In fact, there are certain ſubſtances which may actually be excited by means of friction, and at the ſame time are pretty good conductors.

The following liſts contain, in general, all the electrics and the conductors, diſpoſed, as much as it is practicable, in the order of their perfection, beginning with the moſt perfect of each claſs.

ELECTRICS.

Glaſs and all vitrifications, even the metallic vitrifications.
All precious ſtones, of which the moſt tranſparent are the beſt.
Amber.
Sulphur.
All reſinous ſubſtances.
Wax.
Silk.
Cotton.

Several

Several dry and external animal ſubſtances, as feathers, wool, hair, &c.
Paper.
White ſugar, and ſugar-candy.
Air, and other permanently elaſtic fluids.
Oils.
Dry and complete oxides of metallic ſubſtances.
The aſhes of animal and vegetable ſubſtances.
Dry vegetable ſubſtances.
Moſt hard ſtones, of which the hardeſt are the beſt.

Almoſt all the above-mentioned ſubſtances, when heated beyond a certain degree, become conductors. Thus red-hot glaſs, melted roſin, &c. are conductors of electricity *. The focus of a burning lens, or concave reflector, is not a conductor. Sometimes glaſs of a hard quality is ſo bad an electric as to be almoſt a good conductor. It is remarkable that often the nature of the ſame pieces of glaſs is changed by time, and by uſe, ſo as to become good electrics, though at firſt they were almoſt conductors, and *vice verſa*.

A glaſs veſſel is excited beſt when the air in it is a little rarefied; but a glaſs veſſel entirely or almoſt entirely exhauſted of air, on being rubbed, ſhews no ſigns of electricity on its external ſurface,

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* Hot air has been reckoned a conductor; but this is denied by Mr. Read. See his Summary View of Spontaneous Electricity, p. 8.

face, but the electric power appears within the veſſel. A glaſs veſſel with condenſed air in its cavity, or full of ſome conducting ſubſtance, cannot be excited; yet a ſolid ſtick or lump of glaſs may be excited.

CONDUCTORS.

Gold.
Silver.
Copper.
Platina.
Braſs.
Iron.
Tin.
Quickſilver.
Lead.

Semi-metals, more or leſs.
Metallic ores, more or leſs.
Charcoal, either of animal or of vegetable ſubſtances *.
The fluids of an animal body.
Water (eſpecially ſalt water), and all fluids, excepting the aërial, and oils.
The effluvia of flaming bodies.
Congealed water, viz. ice or ſnow. But when cooled down to —13° of Fahrenheit's thermometer, Mr. Achard of Berlin found that ice loſt its conducting property, and became an electric.

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* Charcoal is very equivocal in its conducting power; for ſome pieces of it will hardly conduct at all, whilſt others are very good conductors.

Several dry and external animal ſubſtances, as feathers, wool, hair, &c.
Paper.
White ſugar, and ſugar-candy.
Air, and other permanently elaſtic fluids.
Oils.
Dry and complete oxides of metallic ſubſtances.
The aſhes of animal and vegetable ſubſtances.
Dry vegetable ſubſtances.
Moſt hard ſtones, of which the hardeſt are the beſt.

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Moſt ſaline ſubſtances, of which the metallic ſalts are the beſt.

Several earthy or ſtony ſubſtances.

Smoke.

The vapour of hot water.

Electricity pervades alſo ſuch a vacuum, or abſence of air as is cauſed by the beſt air-pump; but not the perfect abſence of air, or the torricellian vacuum, formed by boiling the quickſilver in a barometer tube *.

It needs hardly be obſerved, that compound bodies partake more of the nature of conductors or of electrics, according as a greater quantity of the former

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* In rarefied air the attraction of electricity is weakened, and the electric light becomes more diffuſed, but leſs denſe, in proportion to the rarefaction; but, though in a very ſmall degree, they are, however, viſible even in the beſt vacuum that can be produced by the moſt efficacious air-pump, viz. when the air which remains in the receiver is about the thouſandth part of the original quantity. All this ſeems natural; for, ſince the air is an electric, the more accurately this electric is removed from a given ſpace, the more effectually can the electric power paſs through it; and hence it might be expected, that the electric power would paſs freely through the perfect torricellian vacuum. But it ſeems to have been fully aſcertained by Mr. Walſh and Mr. Morgan, that ſuch a vacuum is not a conductor of electricity. See Mr. Morgan's Paper in the Philoſophical Tranſactions, vol. 75th, and my Treatiſe on Electricity, fourth edition, Part IV. Chap. VIII.

former or of the latter enters into their compoſition. Thus green vegetables, freſh wood, &c. are conductors on account of the water which they contain. Hence it follows, that all electrics, previouſly to their being uſed as electrics, muſt be properly cleaned and dried.

Baked wood is a very good electric, but it ſoon loſes that property by imbibing moiſture from the air: hence, in order to preſerve it in a non-conducting ſtate, it ſhould be varniſhed as ſoon as it comes out of the oven; and then again thoroughly dried in a warm place, or in the oven itſelf.

CHAP. II.

OF THE TWO ELECTRICITIES.

IF the perſon who rubs the glaſs tube, as mentioned in the preceding chapter, be inſulated, viz. be ſuſpended by means of ſilk ſtrings, or ſtands upon a cake of roſin, &c. and in that ſituation rubs the tube with his hand; after a few ſtrokes it will be found that the perſon and the glaſs tube are both electrified; for if any light bodies be preſented to any part of the perſon's body, they will be attracted and repelled in the ſame manner as they are by the tube. The inſulated perſon will alſo give out ſparks to another conductor that may be preſented to any part of his body; but the electricity of the inſulated perſon is different from the electricity of the tube, and the difference principally conſiſts in the following three characteriſtic properties.

I. Whenever an inſulated light body, as for inſtance, a ſmall piece of cork ſuſpended by a ſilk thread, has been attracted by the tube, and afterwards repelled; that cork will not be attracted again by the excited tube, but will be repelled by it,

provided

provided the cork in this ſtate of repulſion is not touched by any conducting body. The ſame thing takes place if an inſulated light body, like the cork, &c. be attracted and repelled by the perſon's body, viz. it will continue to be repelled by it. But if the inſulated cork, which is actually repelled by the tube, be brought near the perſon, a ſtrong attraction will take place between the cork and the perſon; and in the ſame manner, if the other cork, which is repelled by the perſon, be brought within a certain diſtance of the tube, the former will be ſtrongly attracted by the latter. Or if the two inſulated corks, which are repelled, viz. one by the tube, and the other by the perſon's body, be brought within a certain diſtance of each other, they will attract, and will ruſh towards, each other.

The ſame thing may be obſerved in a more convincing manner, by preſenting more than one light body to each of the electrified bodies. Thus let A, B, fig. 2, Plate XXIII. be two cork balls faſtened by a linen thread ACB, and let the part CD be a ſilk thread faſtened to a proper ſupport, at ſome diſtance from the wall or other object. In this ſituation, if you bring the excited glaſs tube near the balls A, B, the tube will attract them, and will ſoon after repel them. Now let the tube be removed, and the cork balls will be found to repel each other, and to remain for a conſiderable time in the ſituation of fig. 3.

Let another ſimilar pair of cork balls be brought quire any electricity, then the other body will certainly acquire the other electricity.

It muſt likewiſe be remarked, that almoſt all the electrics may be made to acquire, at pleaſure, the one or the other of the two electricities; viz. by uſing particular rubbers. Thus, if a glaſs tube be drawn acroſs the back of a cat, it will acquire the reſinous electricity; but if rubbed with any other ſubſtance, it will then acquire the vitreous electricity. Thus alſo a ſtick of ſealing-wax will acquire the vitreous electricity, when rubbed with any metallic ſubſtance; but it will acquire the reſinous electricity when rubbed with leather, or paper, or the human hand, &c.

A ſlight alteration, either of temperature, or of ſurface, or of preſſure, will diſpoſe a body to acquire one electricity rather than the other; the rubber always acquiring the oppoſite electricity.

When the difference between the two electricities was firſt obſerved, it was imagined that the two powers were both owing to emanations of two particular elaſtic fluids, which, when mixed in due proportion, would counteract each other, or would form a ſort of neutral compound. But a ſuppoſition much ſimpler, which goes under the name of the Franklinian theory, and which is peculiarly corroborated by the above-mentioned third difference between the two electricities, viz. that of the current from the vitreous to the reſinous electricity, is as follows:

All

All the phenomena, called electrical, are ſuppoſed to be produced by an inviſible and ſubtile fluid exiſting in all the bodies of the terraqueous globe. It is alſo ſuppoſed that this fluid is very elaſtic, viz. repulſive of its own particles, but attractive of the particles of other matter.

When a body does not ſhew any electrical appearances, it is then ſuppoſed to contain its natural quantity of this electric fluid; (but whether that quantity bears any proportion to the quantity of matter, or not, is utterly unknown) therefore, that body is ſaid to be in its *natural*, or *non-electrified ſtate*: but if a body ſhews any electrical appearances, it is then ſaid to be *electrified*, and it is ſuppoſed that it has either acquired an additional quantity of electric fluid, or that it has loſt ſome of its natural ſhare. And from the above-mentioned circumſtance of the current, &c. (page 347,) we are led to ſuppoſe that the vitreous electricity ariſes from an over-charge of that fluid, and that the reſinous electricity ariſes from an under-charge, or diminution of the natural quantity of that fluid. Hence the vitreous electricity has alſo been called the *plus*, or the *poſitive electricity*; and the reſinous has been called the *minus*, or the *negative electricity* *.

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* I need not mention any other of the numerous hypotheſes that have been offered in explanation of the electrical phenomena, as they are too deficient to deſerve any particular notice.

As this hypotheſis is ſufficient to account for all the electrical appearances, at leaſt much more ſo than any other, we are authorized to adopt it, until ſome other hypotheſis may ſeem to be better entitled to our aſſent.

In the firſt place, this theory ſhews that when an electric and a conducting ſubſtance are rubbed againſt each other, the electric fluid is not generated; but, by the action of rubbing, one body pumps, as it were, the electric fluid from the other body. Hence, if one body becomes overcharged with it, or electrified poſitively, the other muſt become undercharged, or electrified negatively, unleſs its deficiency is ſupplied by other bodies that communicate with it*. Hence alſo we ſee the reaſon why, when an electric is rubbed with another electric, or with an inſulated rubber, it can acquire but little electricity, viz. becauſe in that caſe the rubber cannot be ſupplied with electric fluid from other bodies.

Electric attraction is eaſily explained; for this does not exiſt, except between bodies that are differently electrified, where the ſuperfluous electric fluid

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* By what mechaniſm one body extracts the electric fluid from another body during the rubbing, is by no means known. The increaſed capacity of the electric for the electric fluid in certain ſituations, ſeems to afford a plauſible explanation. The nature of thoſe capacities will be explained hereafter.

fluid of the bodies that are electrified poſitively attracts, according to the theory, the undercharged matter of thoſe which are electrified negatively.

We might now proceed to apply this theory to the other phenomena of electricity; but it will be more ſatisfactory to ſubjoin this application to the deſcription of the experiments which will be given in the courſe of this Section.

CHAP. III.

OF COMMUNICATED ELECTRICITY, PARTICULARLY TO CONDUCTORS.

WHENEVER any electricity is communicated to a body, be it poſitive or negative, it is confined upon it only by electrics, and will remain with that body a longer or a ſhorter time, according as the electrics which confine it are more or leſs perfect. Thus the electricity which is ſuperinduced upon a glaſs tube by rubbing it, remains upon the tube, inſomuch as it is ſurrounded by the air, which is an electric; and as the air is in a more or leſs perfect electric ſtate on account of its moiſture, dryneſs, &c. ſo the electric virtue is retained upon the glaſs for a longer or a ſhorter period; and ſometimes an excited glaſs tube will remain ſenſibly electrified for upwards of 20 hours.

If a finger, or any other conductor, be preſented to an excited electric, it will receive a ſpark, and in that ſpark a certain portion only of the electricity of the excited electric, becauſe that electric cannot convey the electricity of all its ſurface to that part to which the conductor has been preſented. Hence, if if a conductor be preſented ſucceſſively to different parts of the excited electric, it will receive a ſpark at every approach, until all the power of that electric is exhauſted, and then a new excitation is neceſſary in order to revive it.

Whenever a conductor, which communicates with the earth, (viz. not inſulated) is preſented at a convenient diſtance to an excited electric, it acquires, on that preſented ſide, an electricity contrary to that which is poſſeſſed by the electric. This electricity increaſes as the body is approached, and at laſt, there being an eager attraction between poſitive and negative electricities, the conductor receives a ſpark from the electric, by which means the balance is reſtored.

If the conductor do not communicate with the earth, but be inſulated, then on being preſented, as before, to the excited electric, not only that ſide of it which is towards the electric, but the oppoſite ſide alſo will appear electrified; with this difference, however, that the ſide, which is expoſed to the influence of the electric, has acquired an electricity contrary to that of the excited electric, and the oppoſite ſide has acquired the ſame electricity as that of the electric. Thoſe two different electricities of the conductor increaſe as the conductor comes nearer to the electric, and at laſt it receives a ſpark from the electric, and becomes throughout poſſeſſed of the ſame electricity with the electric.

All thoſe effects will take place in the ſame manner, if a thin plate of glaſs, or of roſin, or of other electric ſubſtance, be interpoſed between the conductor and the excited electric; but then a ſpark cannot come from the electric to the conductor, unleſs it opens its way by burſting the interpoſed electric, as it always does in paſſing through the air. This diſplacing and ſubſequent collapſing of the air is what cauſes the noiſe that attends a ſpark.

An inſulated conductor that has received the electricity from an excited electric (in which ſtate it is ſaid to be *electrified by communication)* will act in every reſpect like the excited electric itſelf, excepting that when it is touched by another conductor which is not inſulated, the former will give one ſpark to the latter, diſcharging at once all its electricity, becauſe the electricity which belongs to every part of its ſurface is eaſily conducted through its ſubſtance to that ſide to which the other conductor is preſented*. Hence it follows that the electricity, which is diſcharged by an electrified and inſulated conductor, is in general ſtronger than that which is diſcharged by an excited electric.

If there be two inſulated conductors, one of

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* It muſt be obſerved, however, that when the electrified conductor is large, and much extended, a very trifling reſiduum of electricity generally remains upon it, which will afford a ſecond, but incomparably ſmaller, ſpark.

which only is electrified, and if this conductor be touched by the other, then the electricity will be divided amongſt thoſe conductors; but it will be divided neither equally nor in proportion to their quantities of matter. But if the conductors be quite alike, and be ſimilarly ſituated with reſpect to the ſurrounding bodies; then the electricity will be divided equally among them. If their ſurfaces be equal but diſſimilar, as for inſtance, a ſquare foot of tin foil in one piece, and another ſquare foot of the ſame cut into a long ſlip; then the latter, viz. the body whoſe ſurface has a greater extenſion, will acquire more electricity than the other. If, when the two conductors are equal and ſimilar, one of them lies contiguous to an imperfect conductor, and the other is contiguous to the air only; then the former will acquire a greater quantity of electricity than the latter.

The electric ſpark (viz. a ſeparate quantity of electricity) will go a greater or leſs diſtance through the air, in order to reach a conductor, according as its quantity is greater or leſs; as the parts from which it proceeds, and on which it ſtrikes, are ſharper or more blunt, and as the conductor is more or leſs perfect.

The noiſe and the light, which accompany the ſpark, are greater or leſs, according to the quantity of electricity, alſo as the parts from which it proceeds, and on which it ſtrikes, are blunter or ſharper, and as the conductor is more or leſs perfect.

fect. Thus a ſharp-pointed body will throw off electricity to, and receive it from a greater diſtance than a body of any other ſhape; but that paſſage occaſions no remarkable noiſe, and is attended with little light; for in this caſe the electricity comes not in a ſeparate large body, but by little and little, or rather in a continuate ſtream.

If a pointed wire be concealed in an open glaſs tube that projects a ſhort way beyond the point, or if it be covered with tallow, or bees-wax, or ſulphur, &c. then it will take a ſtrong ſpark from an electrified conductor.

It is remarkable, that when points are throwing off, or are receiving electricity, a current of air always appears to proceed from the point, and that is the caſe whether the electricity is poſitive or negative.

A pretty large quantity of electricity pervades the ſubſtance of a conductor of conſiderable length with ſurpriſing and inappreciable velocity; but a ſmall quantity of it has been found to take a little time in paſſing through a long and leſs perfect conductor.

The electric ſpark taken upon any part of a living animal body, cauſes a diſagreeable ſenſation, which is more or leſs ſo, according as the ſpark is ſtronger or weaker, and as the part is more or leſs delicate, or the perſon more or leſs ſenſible.

It has been repeatedly aſſerted and denied, firſt, that electricity communicated to inſulated animal bodies, quickens their pulſe, and increaſes their perſpiration; 2dly, that if it be communicated to inſulated fruits, fluids, and other bodies which are actually in a ſtate of evaporation, it increaſes that evaporation; and, 3dly, that it promotes vegetation.

With reſpect to the firſt circumſtance, the moſt accurate experiments ſhew that electrization, whether by poſitive or negative electricity, does not accelerate nor retard the ordinary number of pulſations in a ſound perſon; but that the quickening of the pulſation, which is often obſerved in ſuch caſes, ariſes from fear or apprehenſion *.

The perſpiration of animal bodies, fruit, and other ſubſtances that are actually in a ſtate of evaporation, is increaſed but little by electrization; provided thoſe ſubſtances are expoſed to the ambient air with a free ſurface.

With reſpect to vegetation, the moſt impartial, diverſified, and concluſive experiments have ſhewn, that electrization does neither promote nor retard vegetable life †.

If the face, or any part of the body, be preſented to an excited electric, or to a conductor ſtrongly

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* See Van Marum's Account of the Teylerian Electr. Mach. of Harlem, and my Treatiſe on Elect. 4th Edition, vol. III. p. 277.

† See Dr. Ingen-Houſz's two Letters in the *Journal de Phyſique*, for February 1786 and May 1788.

electrified, a ſenſation will be felt as if a wind were blowing, or rather as if a ſpider's web were drawn over it.

If the noſtrils be preſented to an excited electric, a ſmell will be perceived which much reſembles that of phoſphorus; but communicated electricity does not occaſion any ſuch ſenſation, except when a large quantity of it paſſes ſuddenly from one body to another.

If the ſtream of electricity which iſſues from an electrified point be directed on the tongue, a peculiar taſte is perceived; and bodies that have been a certain time expoſed to that ſtream, or to ſtrong electric effluvia in general, retain a certain ſmell, ſuch as has been mentioned above, for a conſiderable time after.

If electricity be communicated to an inſulated veſſel containing water, and the water be actually running out of it through a hole or pipe; the ſtream, if leſs than a tenth of an inch in diameter, will be accelerated, and more ſo in proportion as its diameter is ſmaller; it will even drive the water in a continuate ſtream out of a very ſmall capillary tube, out of which, without the aid of electricity, the water will not even be able to drop. When above a tenth of an inch in diameter, the ſtream, though it divides and carries the fluid farther, is, however, neither ſenſibly accelerated nor retarded by electricity.

Towards the beginning of this chapter it has been

been ſaid, that when a conductor is preſented to an electrified body, it acquired, on the preſented ſide, an electricity contrary to that of the electrified body. We muſt now add a very remarkable law, viz. that no electricity can be obſerved upon the ſurface of any electrified body, unleſs that ſurface is contiguous to an electric, which can in ſome manner or other acquire the contrary electricity at a little diſtance; or, in other words, no electricity can appear upon the ſurface of any electrified body, unleſs that ſurface is oppoſite to another body which has actually acquired the contrary electricity; and thoſe contrarily electrified bodies muſt be ſeparated by an electric. Thus, when an inſulated body, which ſtands at a diſtance from other conductors, is electrified, the air which ſurrounds it performs at once the office of an electric and of a conductor; for it acquires the contrary electricity at a little diſtance from the electrified body, whilſt the intervening ſtratum of air ſeparates thoſe two electricities.

With reſpect to the paſſage of electricity from one body to another, we may in general remark, that if the repulſion exiſting between bodies that are poſſeſſed of the ſame kind of electricity be excepted, all the other electrical phenomena are produced by the paſſage of electricity from one body to another.

With reſpect to attraction and repulſion, this general law muſt be remembered; namely, that thoſe bodies, which are poſſeſſed of the ſame ſort of electricity, repel, or tend to repel, each other; but bodies, which are poſſeſſed of different electricities, attract, or tend to attract, each other; and there is no electric attraction but between bodies which are poſſeſſed of different electricities [*].

This laſt aſſertion may at firſt ſight appear to be contradicted by the effect which takes place when ſmall bodies are preſented to an excited tube, or to any other electrified body; for they are attracted by it, though they have not been previouſly expoſed to any electrization; but the difficulty will vaniſh, if what has been ſaid above be remembered, namely, that the ſmall bodies naturally acquire the contrary electricity merely by their being brought within the ſphere of action of an electrified body; ſo that when they are attracted, they are actually poſſeſſed of the contrary electricity.

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[*] A particular explanation of this law will be given hereafter.

CHAP. IV.

OF ELECTRICITY COMMUNICATED TO ELECTRICS, AND OF THE LEYDEN PHIAL.

THE electric virtue may alſo be communicated to electrics; but this communication to electrics is attended with ſeveral circumſtances, different from thoſe which attend the communication of electricity to conductors; for when one ſide of any of the latter receives ſome electricity, that electricity inſtantly pervades its whole ſubſtance; whereas when an electric is preſented to an electrified body, a ſpark from the latter will electrify the former in a ſmall ſpot only; for, on account of its non-conducting quality, the electricity cannot expand itſelf through it. In ſhort, when an electric is preſented to an electrified body, the former will acquire different electricities on different ſides, (as has been ſaid of conductors in the preceding chapter); theſe electricities increaſe according as the diſtance between the two bodies diminiſhes, viz. as they are brought nearer; but if at laſt a ſmall quantity of electricity be communicated to one part of the electric, that electric will not become throughout

out poſſeſſed of one electricity, but will, in ſome caſes, ſtill ſhew different electricities on different ſides; and in certain circumſtances many repeated changes from poſitive to negative electricity may be obſerved upon the very ſame electric.

If to one ſide of an electric ſufficiently thin, ſuch as a pane of common window glaſs, a plate of ſealing wax, or of talc, &c. you communicate one electricity, and to the oppoſite ſide you communicate the contrary electricity, that plate in that ſtate is ſaid to be *charged*, and the two electricities cannot come together, and annihilate each other, unleſs a communication by means of conducting ſubſtances be made between both ſides, or the electric plate be broken by the force of electric attraction.

When the two electricities of a charged electric are by any means united, and of courſe their powers deſtroyed, then that electric is ſaid to be diſcharged; and the act of union of thoſe two oppoſite powers is generally called the *electric ſhock*; becauſe when a living animal body forms the circle of communication between the two ſides of the charged plate, the diſcharge which muſt paſs through it, occaſions a ſudden motion, by contracting the muſcles through which it paſſes, and gives a peculiar ſenſation, which proves more or leſs diſagreeable according to the different conſtitutions of perſons.

In order to avoid the difficulty of communicating electricity to an electric plate, it is cuſtomary to coat the ſides of it with ſome conducting ſubſtance, ſuch

ſuch as tin-foil, gold-leaf, ſheet-lead, &c. by which means the charging and diſcharging becomes very eaſy; for when the electricity is communicated to one part of the coating, it immediately ſpreads itſelf through all the parts of the electric that are in contact with that coating; and when the electric is to be diſcharged, it will be ſufficient to make a conducting communication between the coatings of both ſides.

Thoſe coatings muſt not come very near to each other towards the edge of the plate, for in that caſe a communication between thoſe coatings is ready at hand; and though the coatings are not abſolutely in contact, yet when they are electrified, the electricity will eaſily force a paſſage through the air, and, by paſſing over the ſurface of the electric plate from one coating to the other, renders it incapable of receiving any conſiderable charge*.

The curious properties of charged electrics, and the ſurpriſing effects of the diſcharges, entitle it to the following more accurate enumeration of particulars.

If a glaſs plate (and the ſame thing muſt be underſtood of other electric ſubſtances), whether ſmooth or rough, be coated with ſome conducting ſubſtance, ſo that the coatings do not come very near

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* The property of conducting the electricity over their ſurface is ſo great in ſome kinds of glaſs, as to render them quite unfit for the purpoſe of charging and diſcharging.

near the edge of the plate; and if ſome electricity be communicated to one of thoſe coatings, whilſt the other coating communicates with the earth, or with a ſufficient quantity of conducting bodies; then the laſt mentioned coating will of itſelf acquire about an equal quantity of the contrary electricity: but if, whilſt one ſide is acquiring electricity, the oppoſite ſide does not communicate with the earth, or with a ſufficient quantity of conducting ſubſtances; then the glaſs plate cannot be charged, except in a very trifling degree.

Now the reaſon why, when one ſide of the glaſs is receiving one electricity, the oppoſite ſide acquires the other electricity, is the ſame as was mentioned above, viz. the property which bodies have of acquiring an electricity contrary to that which is poſſeſſed by a contiguous electrified body; and the interpoſition of the glaſs plate keeps thoſe electricities ſeparate: but if the charge be too high, and the glaſs plate be too thin, then the great attraction between the two different electricities forces a paſſage through the glaſs, diſcharges it, and, by breaking it, renders it unfit to receive another charge.

Thoſe effects take place in the ſame manner if the glaſs be not in the form of a plate, but in any other ſhape whatſoever, provided it be ſufficiently thin; it being not the form but the thickneſs of the glaſs that renders it capable of receiving an higher or a lower charge. The thinner glaſs receives the higheſt charge, but it is more liable to be broken by it.

This remarkable property was diſcovered by Von Kleiſt in 1745*, but it was firſt ſatisfactorily noticed at Leyden, where the experiment was performed with a phial; hence a phial or bottle coated on the inſide and outſide for the purpoſe of charging, &c. has been called the *Leyden Phial*, otherwiſe an *electric jar*; and the charging and diſcharging of a coated electric, in general, has been called the *Leyden Experiment.*

A coated glaſs is capable of holding a greater charge in condenſed than in rarefied air, provided the air be dry.

If a coated glaſs plate or jar, after having been charged, be inſulated, and only one of its coatings, or ſides, be touched with ſome conductor; that ſide will not part with its electricity, becauſe the electricity of one ſide exiſts in conſequence of the contrary electricity on the oppoſite ſide, and they, by their mutual attraction, confine each other on the ſurface of the glaſs. Therefore, in order to diſcharge that glaſs, both coatings muſt be connected by means of a conducting body, and then the diſcharge is made through that conductor. The diſcharge may alſo be made by connecting each coating with a large quantity of conducting bodies.

When, in order to diſcharge a jar, one of its coatings is touched firſt with a conductor, as for inſtance, with one end of a braſs chain, no particular

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* Prieſtley's Hiſt. of Elect. 3d edit. vol. I. p. 102.

phenomenon

phenomenon will take place; but as ſoon as the other end of the chain comes within a ſufficient diſtance of the other coating, a ſpark will be ſeen between this end of the chain and that coating, accompanied with a report, and the jar is inſtantly diſcharged.

The ſpark thus produced by the diſcharge of a charged electric or Leyden phial, is much brighter, much louder, but at the ſame time much ſhorter than that which is taken from an inſulated conductor that contains an equal quantity of electricity.

If the communication between the two coatings of a charged jar be made by means of imperfect conductors, as a ſlender piece of wood, or wet packthread, &c. the diſcharge will be made ſilently, but not ſo ſuddenly, and of courſe its effects will not be ſo great, as when it is diſcharged ſuddenly.

The force of the ſhock, which is produced by coated glaſs of a given thickneſs, is proportionate to the quantity of coated ſurface, ſuppoſing that the charge has been carried up to the utmoſt degree. Hence by increaſing the quantity of coated ſurface, the charge, and the effects of the diſcharge or ſhock, may be increaſed almoſt to any degree. A number of coated jars, connected together in ſuch a manner as to unite their forces and act like one jar, conſtitutes what is called an *electrical battery*.

In making the diſcharge, the electricity, which goes from one ſide of the jar to compenſate the contrary electricity of the oppoſite ſide, through good

good conductors, has been found to move with inappreciable quickneſs *.

The force and the noiſe of an electric diſcharge is not affected by the inflections of the conductor through which it paſſes, but is ſenſibly weakened by its length.

It evidently appears that the electricity finds ſome obſtruction in going through even the beſt conductors; for in ſome caſes it will prefer a ſhort paſſage through the air, to a long one through the beſt conductors. The obſtruction is greater where the conductors, which form the circuit, are not in perfect contact, and eſpecially where the electricity muſt paſs from a more perfect to a leſs perfect conductor.

A ſtrong ſhock ſent through an animal or a plant, puts an end to animal as well as to vegetable life †. If a ſmall interruption of the circuit be made in water, on making the diſcharge (notwithſtanding that the water is a conductor) a ſpark will be ſeen in it, which never fails to agitate the water, and often breaks the veſſel that contains it. If, by making a ſmall interruption of the circuit between

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* Prieſtley's Hiſtory of Electricity, Period VIII. Sect. II.

† The common *Balſam* (*Impatiens*) is the plant which, as far as I know, is killed eaſieſt by electricity. The ſhock of a ſmall jar, ſuch as a coated 4 ounce phial, is ſufficient to deſtroy the life of a full grown balſam. The plant begins to droop immediately after the ſhock.

the two ſides of a Leyden phial, in water, the ſhock is paſſed through it, ſo as to produce a ſpark in the water, that diſcharge will be found to produce an exceedingly ſmall bubble of elaſtic fluid; and, by repeating the diſcharge a vaſt number of times, a certain quantity of that elaſtic fluid may be accumulated, which is inflammable, and appears to be a mixture of hydrogen and common air or oxygen air, viz. the components of water. By inflammation this elaſtic fluid explodes, and is converted again into water *.

If the circuit be interrupted by one or more electrics, or imperfect conductors, of a moderate thickneſs, the electric ſhock will break them, and in ſome circumſtances will diſperſe them in every direction, and in ſuch a manner as if the force proceeded from the centre of every one of the interpoſed bodies. In ſeveral inſtances the effect of the ſhock upon an interpoſed body is evidently greater on that ſide of it which communicates with the poſitive ſide of the jar or battery.

A ſtrong ſhock ſent through a ſlender wire, or a ſmall piece of metal, makes it inſtantly red-hot, melts it, and, when the fuſion is perfect, reduces it into

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* See a letter on the ſubject from Meſſrs. Pacts, Van Trooſtwyk, and Deiman, to Mr. De la Metherie, or my Treatiſe on Electricity, 4th edition, vol. III. page 168. Alſo Dr. Pearſon's Paper in the Philoſophical Tranſactions, Volume for the Year 1797, page 142.

into globules of different ſizes, or even into a ſcoria. If the metal be placed between pieces of glaſs, the ſhock, by melting it, will force it into the very ſubſtance of the glaſs. The glaſſes themſelves are generally ſhattered to pieces.

If thoſe glaſſes which incloſe the metal be preſſed by heavy weights, then a remarkably ſmall ſhock is often capable, not only of ſhaking off the weights, but alſo of breaking ſuch thick glaſſes as otherwiſe would require the force of a large battery. A thick piece of glaſs may likewiſe be broken into innumerable fragments, by only ſending a ſhock over a ſmall part of its ſurface, when that part is preſſed by weights, without the interpoſition of any metal. When ſuch pieces of glaſs are not broken by the exploſion, they then will frequently be found marked with the moſt lively priſmatic colours, which lie ſometimes confuſed, and at other times in their priſmatic order. The coloured ſpot is evidently owing to thin plates or ſcales, partly ſeparated from the glaſs; and it generally occupies a ſpace of about one inch in length, and half an inch in breadth.

schilfer

The force which is required to melt wires of the ſame metal, muſt be greater or leſs, according to the length and thickneſs of the wire; but it is far from bearing any direct proportion to the quantity of metal; for if a wire of a certain length and diameter be barely melted by a large battery, a wire of equal length and twice the ſubſtance cannot perhaps be melted by leſs than ten ſuch batteries.

When a moderate ſhock (meaning a ſhock that is not ſufficient to melt the metallic circuit) is ſent through an imperfect metal, eſpecially when the circuit conſiſts of ſeveral pieces, as a chain; a black duſt, in the form of ſmoke, will proceed from that metal, which is a metallic oxide. If ſuch circuit be laid upon paper, glaſs, or other non-conductor, this, after the exploſion, will be found ſtained with indelible marks, and often ſhews evident ſigns of having been burnt. A long and permanent track may be marked upon glaſs, and upon ſeveral other bodies, eſpecially upon certain painted ſurfaces, by paſſing an electric ſhock over their ſurfaces *.

A ſhock ſent through ſeveral metallic oxides, when theſe form part of the circuit, frequently reduces them into the metallic ſtate.

A ſufficiently ſtrong ſhock ſent through a magnet has ſometimes deſtroyed its virtue, and at other times has invigorated it, or even reverſed its poles. The following particulars will ſhew the circumſtances that are likely to produce ſuch effects. When the charge of eight feet of coated glaſs ſurface, or even leſs, is ſent through a fine ſewing-needle, the needle will thereby often acquire a magnetic polarity,

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* See my Treatiſe on Electricity, 4th edition, vol. II. page 59.

ſo as to traverſe when laid gently upon water. If the needle be ſtruck, laying eaſt and weſt, then that end of it which is entered by the ſhock, viz. that which communicates with the poſitive ſide of the battery, or jar, will afterwards point north; but if the needle be ſtruck laying north and ſouth, then that end of it which ſtands towards the north will, in any caſe, point north, and the needle will acquire a ſtronger virtue in this than in the former caſe; and laſtly, if the needle be ſet ſtraight up, and the electric ſhock enters it at either point; then the lower extremity of the needle will acquire the property of pointing north *. This however cannot take place in all parts of the world, for a reaſon which will appear in the next ſection.

A ſmall ſhock is ſufficient to inflame ſeveral inflammable ſubſtances; and inflammable ſpirits may be fired even by a ſpark proceeding from an electrified conductor.

If the moderate charge of a large battery be diſcharged between two ſmooth ſurfaces of metallic bodies, laying at a ſmall diſtance from each other; or if the exploſion of a battery, iſſuing from a pointed body, as the point of a needle, be repeatedly taken upon the ſmooth and plain ſurface of a metallic body, ſituated at a little diſtance from the point; in either caſe the metallic ſurface or ſurfaces

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* See Franklin's Letters, p. 90, and Beccaria's Art. Elec. §. 731 to 734.

will be found marked with circles of partly ſcaled or fuſed metal round a central ſpot, and, eſpecially in the latter caſe, they will frequently exhibit all the priſmatic colours *.

When the diſcharge of a battery is made by bringing the conductors which proceed from the coatings of a battery, in contact with, or at a little diſtance from, the ſurface of certain conducting ſubſtances, as water, raw meat, moiſt wood, &c. the electricity, inſtead of going through thoſe ſubſtances, will go over their ſurface in a luminous track; ſometimes preferring a much longer paſſage over the ſurface to a ſhort one through the ſubſtance. In this caſe the exploſion never fails to give a concuſſion to the body over which it paſſes.

The electric exploſions taken upon the leaves of delicate flowers frequently change their colours †.

The colour of the electric ſpark, when taken in hydrogen or in ammoniac gas, is purple; in carbonic acid gas it appears white.

The electric ſpark taken repeatedly in common air, diminiſhes a little its purity. In other permanently elaſtic fluids ſometimes it increaſes, and in others it diminiſhes, their bulk, and alters their quality in a certain degree ‡.

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* For farther particulars concerning thoſe circles, ſee the Phil. Tranſ. vol. 58.

† Prieſtley's Hiſtory of Elect. P. VII.

‡ See Dr. Prieſtley's ſecond vol. of Obſervations on different kinds of air; and Dr. van Marum's Account of Experiments with the Teylerian Elec. Machine at Harlem.

By making the electric diſcharge a great many times in a mixture of oxygen and common air, or of oxygen air and azotic gas, the nitrous acid is produced *.

According to the theory, the electric fluid which is communicated to one ſide of the glaſs drives away the electric fluid from the other ſide, or the electricity of one ſide induces a contrary electricity on the oppoſite ſide; but it is impoſſible to ſay how this virtue or this repulſion can operate through the glaſs, which is impervious to the electric fluid; much leſs do we know where the ſuperinduced electric fluid reſides.—Is it lodged in the ſurface of the glaſs, or in the air contiguous to the glaſs? In the firſt caſe, if the additional electric fluid penetrates a certain way into the ſubſtance of the glaſs, it follows, that a plate may be given ſo thin as to be permeable to the electric fluid, and of courſe incapable of a charge; yet glaſs balls blown exceedingly thin, viz. about the 600th part of an inch thick, when coated, &c. were found capable or holding a charge †.

Mr. Canton charged ſome thin glaſs balls about 1 ½ inch in diameter, having necks or tubes of about

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* See Mr. Cavendiſh's Experiments, which produced this remarkable diſcovery, in the 75th and 78th volumes of the Philoſophical Tranſactions. See alſo the Phil. Tranſ. for 1800, p. 190, and 202.

† The charging of a jar does by no means diſplace the air from its inſide; neither does the charge heat or cool it.

nine inches in length, and afterwards ſealed the ends of the tubes hermetically. If thoſe balls were preſented to an electrometer, they ſhewed no ſign of electricity; but if they were warmed, by being kept a ſhort time before the fire, then they appeared to be ſtrongly electrical, and appeared poſſeſſed of that electricity which had been communicated to their inſide; which ſhews that heat renders the glaſs permeable to the electric fluid. This electricity is not that which properly conſtitutes the charge, but is the ſuperfluous electricity of their inſide; for an electric jar may always retain a little more electricity on one ſide, than what is juſt ſufficient to counteract the electricity of the oppoſite ſide. If a charged jar be inſulated, and then be diſcharged by connecting its coatings with an inſulated diſcharging rod, after the diſcharge, both theſides of the glaſs together with the diſcharging rod, will be found ſlightly poſſeſſed of the electricity contrary to that of that ſide of the jar which was touched laſt.

Some very remarkable phenomena, the cauſe of which is far from being clearly underſtood, are exhibited by flat glaſs plates, jointly charged like a ſingle plate. If two flat glaſs plates be placed one upon the other, and their outward ſurfaces be coated with tin-foil, in the uſual manner of coating a ſingle plate for the Leyden experiment; and if theſe be charged by preſenting one coating to an electrified body, and communicating the other with the earth; the plates (which we ſhall call A and B) after the charge will adhere firmly to each other; but if ſeparated, A, whoſe coating was charged poſitively, will appear poſitive on both ſides, and B negative on both ſides. If theſe plates be laid one upon the other as before, and be diſcharged, by making a communication between the two coated ſides; they will afterwards be found ſtill to adhere to each other, and if ſeparated, they will ſtill appear to be electrified, but with this remarkable difference, viz. that A is negative on both ſides, and B poſitive on both ſides. If, after the diſcharge, the ſeparation be made in the dark, flaſhes of light will be perceived between their internal ſurfaces. By laying the plates together, touching their coatings, and ſeparating them ſucceſſively, the flaſhes may be obſerved for a conſiderable number of times, diminiſhing by degrees until they vaniſh.

But thoſe effects are not conſtantly the ſame with all ſorts of glaſs. Crown glaſs and common plate glaſs exhibit the above-mentioned phenomena; but it was obſerved by Mr. Henly, that Dutch glaſs plates, when treated in the ſame manner, have each a poſitive and a negative ſide. He alſo obſerved ſome other irregularities. Beccaria endeavoured to account for thoſe and ſimilar phenomena by ſuppoſing that when two bodies, either a conductor and an electric, or two contrarily and equally electrified electrics, are put one upon the other, they adhere to each other, and their electricities diſappear, becauſe the two oppoſite powers counteract each other;

other; but as ſoon as they are ſeparated, the electrics ſhew a power or a tendency to recover their electricities. This is what he called *vindicating electricity* *.

We ſhall laſtly obſerve, with reſpect to communicated electricity, that the application of it either as ſimple electrization, or in the form of ſparks and ſhocks to the human body, has been found unqueſtionably ſerviceable in various diſorders, ſome of which had reſiſted every other medical application. But it muſt at the ſame time be confeſſed that this application is not frequently ſucceſsful to any remarkable degree.

Without entering into any particular diſcuſſion reſpecting its power, or the particular effects which are attributed to it in particular diſorders, I ſhall in general obſerve, that the application of electricity has moſtly proved beneficial in recent caſes of obſtruction, whether of motion, of circulation, or of ſecretion; and that a gentle application has, upon the whole, proved more advantageous than ſtrong ſhocks.

The moſt general practice is to inſulate the patient, to place him in contact with the electrified conductor, in the manner which will be ſhewn hereafter, and then either to preſent a pointed body

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* For farther particulars relative to this vindicating electricity ſee Beccaria's Art. Elec. Part II. Sec. VI. or my Treatiſe on Elec. 4th edition, vol. II. Appendix N° I.

towards the part affected, (which produces rather an agreeable ſenſation, and is called *giving the electrical aura*) ; or to draw ſparks from the part, or at moſt to paſs very ſlight ſhocks through it.

The novice in this branch of natural philoſophy can hardly underſtand the meaning of ſeveral facts that are mentioned in this and the preceding chapters of this ſection. They have been put together for the ſake of reference, and in order that the leading principles of the theory might be ſeen under one point of view ; but the experiments which will be deſcribed in the ſequel will probably remove every difficulty.

CHAPTER V.

DESCRIPTION OF THE ELECTRICAL APPARATUS.

THE electrical apparatus conſiſts of inſtruments neceſſary either for producing electricity, or for accumulating, retaining, and employing it; or laſtly, for meaſuring its quantity and aſcertaining its quality.

The principal inſtrument for the production of electricity is a machine capable, by any means, of exciting an electric, ſo as to produce electrical appearances. The moſt eſſential parts of this machine are the electric, the moving engine, the rubber, and the prime conductor, viz. an inſulated conductor, which immediately receives the electricity from the excited electric.

The electric was formerly uſed of various ſubſtances and various ſhapes. At preſent glaſs globes, or glaſs cylinders, or circular glaſs plates, are almoſt all the variety that is uſed, and which indeed are the moſt advantageous. The moſt uſual ſize for the globes is from 9 to 12 inches in diameter; and they are moſtly made with one neck. The cylinders are

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made with two necks, and they are of all ſizes, even as far as 24 inches in diameter. The glaſs plates are alſo of various ſizes. The glaſs generally uſed in this country for ſuch purpoſes is the beſt flint glaſs, and the articles ſhould be well annailed.

With reſpect to the engine, which is to give motion to the electric, multiplying wheels have been generally uſed, which might move the electric with conſiderable velocity, whilſt they are commodiouſly turned by a winch. A wheel and an endleſs ſcrew has alſo been uſed, but this is apt to make a rattling noiſe, and ſoon wears away. But either a cylinder or a circular plate may be moved quite quick enough by means of a ſimple winch, to which the hand is immediately applied.

The rubber is the next article which muſt be deſcribed. After a variety of trials it appears that the beſt rubbers for a globe or a cylinder are made of leather ſtuffed with hair, and a pretty long piece of fine ſilk is faſtened to one ſide of the rubber, and after having paſſed over the rubber, viz. between the cuſhion and the globe or cylinder, ſpreads over more than one third part of the circumference of the latter. For a plate the rubbers moſtly conſiſt of a piece of leather with a piece of ſilk at its extremity, or of cuſhions, &c.

The proper conſtruction of the rubber requires, that the ſide of it which the ſurface of the glaſs enters in whirling, may be as perfect a conductor as poſſible, in order to ſupply the glaſs with electric fluid,

fluid, and that its other ſide be as much a non-conductor as poſſible, in order that none of the fluid which is accumulated upon the glaſs may return to the rubber.

The rubber ſhould be ſupported by a ſpring, by which means it may eaſily ſuit the inequality of the glaſs, and the ſpring ſhould be fixed faſt upon a glaſs pillar or other inſulating ſtand; it being uſeful to have the rubber inſulated in ſeveral experiments; but when its inſulation is not required, a chain or wire is eaſily ſuſpended to it, and thus it may be made to communicate with the earth, or with any other body at pleaſure.

The *prime conductor* is nothing more than an inſulated conductor which is ſituated with one of its extremities contiguous, but not quite in contact, with the electric, and nearly oppoſite to the rubber. This conductor may be made of hollow braſs, or of tin plates, or of paſteboard covered with tin-foil, or of wood covered with tin-foil, &c. Its ſhape is generally cylindrical with ſemi-globular terminations. But be the ſhape what it may, care ſhould be had to make it as free as poſſible from points, ſharp corners, ſharp edges, &c. for theſe throw off and diſſipate the electric fluid; but on the end which is contiguous to the electric, it muſt have a ſhort pointed wire, or two, or more, which are called the *collector*, and will readily receive the electricity.

The ſize of the conductor ſhould be proportionate to the ſize and power of the electric. The larger the prime conductor is, the denſer and longer ſparks may be drawn from it, provided the electric be ſufficiently powerful. But beyond a certain ſize, the diſſipation from the ſurface may be greater than what the electric can ſupply, and in that caſe the large conductor is diſadvantageous.

Upon thoſe principles electrical machines of a vaſt variety of ſhapes and ſizes have been conſtructed in this as well as in other countries. But amongſt all that variety, we ſhall deſcribe two only, which, upon the whole, are the moſt commodious, and are more generally uſeful.

Fig. 4. Plate XXIII. repreſents an electrical machine of the ſimpleſt ſort. GEF is a ſtrong board, which ſupports all the parts of this machine, and which may be faſtened to a ſtrong table by means of one or more iron or braſs clamps, as at Q. The glaſs cylinder AB, quite clean and dry in its inſide, is about 10 inches in diameter, and is furniſhed with two caps, either of wood or braſs, into which its two ſhort necks are firmly cemented *. Each of thoſe caps has a pin, or projection, or pivot, which turns in a hole through a wooden piece, that is cemented on the top of a glaſs pillar, as at A and B on the glaſs pillars BE, AG, which are firmly fixed to the bottom board GEF. One of the above-mentioned

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* The beſt cement for this purpoſe is made by melting and incorporating together 5 parts of roſin, 4 of bees-wax, and 2 parts of powdered red ochre.

tioned projections paſſes quite through the wooden piece, as at A, and has a ſquare termination, to which the winder A D is applied and ſecured on by means of a ſcrew nut. Then by applying the hand at D, the operator may turn the cylinder, &c. Sometimes the part AC of the winder is made of glaſs, in order the more effectually to prevent the eſcape of the electric fluid from the cylinder. I R is the rubber, and IRK is the ſilken flap [*]. This cuſhion or rubber is faſtened to a ſpring which proceeds from a ſocket cemented on the top of the glaſs pillar S. The lower part of this pillar is fixed into a ſmall board which ſlides upon the bottom board of the machine, and by means of a ſcrew nut and a ſlit at H, may be fixed more or leſs forward, in order that the rubber may preſs more or leſs upon the cylinder. NF is a glaſs pillar which is fixed in the bottom board, and ſupports the prime conductor ML, of hollow braſs or tin plates, which has the collector or pointed wires at L, and a knobbed wire at M. From this braſs knob O, a longer ſpark may be drawn than from any other part of the conductor. But this knobbed wire is only ſcrewed into the conductor, and may be eaſily removed from it.

As glaſs is apt to attract moiſture from the air, in which caſe it conducts the electricity over its ſurface; therefore it is proper to cover with ſealing-

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[*] The ſilk generally uſed for this purpoſe is what is commonly called *black mode.*

wax, or to varniſh over, the glaſs pillars of this machine, as alſo all thoſe glaſs articles which ſerve for inſulating; for when varniſhed, and eſpecially when covered over with ſealing-wax in the dry way, they attract the moiſture, either not all, or in an incomparably ſmaller degree, and of courſe they inſulate vaſtly better *.

The ſimple rubber, ſuch as has been deſcribed, will produce a very ſlight excitation of the cylinder; but its power is vaſtly increaſed by laying upon it a little amalgam of tin, and eſpecially an amalgam of zinc †. The beſt way of uſing this emalgam is as

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* In order to cover glaſs with ſealing-wax in the dry way, warm the glaſs gradually near the fire, and when ſufficiently warm, rub a ſtick of ſealing-wax gently over its ſurface; for by this means the ſealing-wax is melted, and adheres to the glaſs. In the humid way, the ſealing-wax muſt be diſſolved in very good ſpirit of wine, for which purpoſe you need only break the ſealing-wax into ſmall bits, and leave it in the ſpirit of wine for a day or two, ſhaking it now and then.—This ſolution muſt be laid upon the dry and clean glaſs, by means of an hair pencil, and when the firſt coat of it is quite dry, then a ſecond, a third, and even a fourth coat ſhould be laid on.

The beſt varniſh for this purpoſe is the amber varniſh, which indeed anſwers as well as the ſealing-wax in the dry way, but it muſt be made with great care and caution.—See the particular deſcription of the proceſs in my Treatiſe on Electricity, 4th edition, vol. III. p. 296.

† The amalgam of tin is made with two parts of quickſilver,

as follows: Firſt make the rubber with the ſilk flap very clean and dry, and put it in its place, as at R I; then ſpread a little of the amalgam upon a piece of leather, and apply it to the under part of the cylinder, while this is revolving in the direction of the letters *a*, B, *c*; for by this means particles of the amalgam will be carried by the glaſs itſelf to the lower part of the rubber, and will increaſe the excitation prodigiouſly. The leather with the amalgam needs not be kept againſt the cylinder longer than it may be required to produce the deſired effect; for when the excitation decreaſes, the leather may be applied again.

The ſimpleſt conſtruction of the plate machine is repreſented by fig. 5, Plate XXIII. which requires very little explanation. ABCDM is a wooden frame, to which the four rubbers are affixed, which

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ſilver, and one of tin-foil, with a ſmall quantity of powdered chalk, mixed together until it becomes a maſs like paſte.

To make the amalgam of zinc, let four or five parts of quickſilver be heated higher than the degree of boiling water, and let one part of zinc be melted in a crucible or in an iron ladle. Pour the heated quickſilver into a wooden box, and immediately after pour the melted zinc into it. Then ſhut up the box, and ſhake it for about half a minute. After this you muſt wait until the amalgam is quite cold, or nearly ſo, and then you may mix it, by trituration, with a ſmall quantity of greaſe, ſuch as tallow or mutton-ſuet, a very ſmall portion of finely powdered whitening, and about a fourth part of the above amalgam of tin.

by means of the ſcrews *g*, *g*, *g*, *g*, may be made to bear with proper preſſure upon the circular glaſs plate HK*. This plate has a hole through its middle, to which an axis ML is firmly fixed, in the manner indicated by the magnified ſide view, fig. 6, and is turned by means of the winch LG. The prime conductor has a branched termination with points at the extremities, which collect the electric fluid from the fore part of the glaſs plate.

Some plate machines have been made with two glaſs plates and eight rubbers, and when properly conſtructed, eſpecially as they are made by Mr. Cuthbertſon, their power is very great. Indeed the moſt powerful electrical machine now extant is, as far as I know, one of this conſtruction made by the above-mentioned philoſophical inſtrument maker, for the muſeum of Teyler, at Harlem; a particular deſcription of which was given to the public by Dr. Van Marum †.

This machine conſiſts of two circular plates, each 65 inches in diameter, fixed on a common axis, parallel to each other, and 7 ½ inches aſunder. Each plate is excited by 4 rubbers; the prime conductor

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* The rubbers generally conſiſt of oblong cuſhions that are frequently affixed to ſprings; but ſometimes they are only pieces of leather ſpread upon wood, to which ſilken flaps are affixed, &c.

† See a compendious deſcription of its effects in my Treatiſe on Electricity, 4th edition, vol. II. p. 273.

is divided into two branches, which enter between the plates, and, by means of points, collect the electric fluid from their inner ſurfaces only.

The plate machines may in general be made more compact and more powerful than other electrical machines, but they are liable to a conſiderable degree of friction, and of courſe they are not eaſily worked.

In the plate machines the rubbers are not eaſily inſulated, yet this has been accompliſhed by various, rather complicated, means *.

Beſides the electrical machine, the operator ought to have ſome glaſs tubes, and one or two pretty large ſticks of ſealing wax, which are of great uſe in a variety of experiments.—The beſt rubber for the excitation of a glaſs tube is the rough ſide of black oiled ſilk, eſpecially when a little amalgam has been rubbed over it; but ſoft new flannel is the beſt rubber for ſealing-wax, ſulphur, rough glaſs, or baked wood; every one of which ſubſtances, when rubbed with flannel, will acquire the negative electricity.

The inſtruments neceſſary for the accumulation of electricity, are coated electrics, amongſt which glaſs has juſtly obtained the principal place. The

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* See the deſcriptions of thoſe machines in letters from Dr. Van Marum to the Chevalier M. Landriani, and to Dr. Ingenhouſz; both printed at Harlem in the years 1789 and 1791.

form is immaterial; but the thickneſs and the quality of the glaſs ſhould be noticed. Thin glaſs can receive a greater charge; but it is at the ſame time more liable to be broken by the diſcharge. A ſingle jar may be pretty thin, but ſuch jars as are to form a large battery muſt be a little thicker. When their openings are narrow, thoſe jars may be coated on the inſide with braſs filings, which are ſtuck by means of gum-water, or paſte, or melted wax; but when their openings are ſufficiently large, they may be coated on their inſide as well as on the outſide with tin-foil, or ſheet-lead, or gilt paper, either of which may be ſtuck with paſte, or varniſh, or gum-water, &c.

Fig. 7. Plate XXIII. repreſents an electric jar, coated with tin-foil on the inſide and outſide, within about three inches of the top of its cylindrical part; and having a wire with a round braſs knob, or ball A, at its extremity. This wire paſſes through the cork or wooden ſtopple D, and its lower extremity touches the inſide coating.

Fig. 8, Plate XXIII. repreſents a battery conſiſting of 16 jars, coated with tin-foil, and diſpoſed in a proper box. The wires, which proceed from the inſide of every four of thoſe jars, are ſcrewed, or ſoldered or faſtened to a common horizontal wire E, which is knobbed at each extremity, and by means of the wires F, F, F, the inſide coatings of 8, or 12, or all the 16 jars may be connected together.

The inſide of the box which contains thoſe jars, is likewiſe lined with tin-foil or tin-plates, for the purpoſe of connecting more effectually the outſide coatings of all the jars. On one ſide of this box there is a hole, through which a ſtrong wire or hook paſſes, which communicates with the lining of the box, and of courſe with the outſide coatings of the jars. To this hook a wire is occaſionally faſtened, which connects it with one branch of the diſcharging rod BBCA.

The diſcharging rod conſiſts of the glaſs handle A, cemented into the braſs ſocket C, and the curved wires B, B, which may be opened and ſhut, like a pair of compaſſes, by a joint at C. The extremities of thoſe wires are pointed, and the points enter the braſs knobs D, D, to which they are ſcrewed, and from which they may be unſcrewed at pleaſure. With this conſtrnction we may uſe either the points or the balls, and the inſtrument may be uſed for diſcharging jars of various ſizes.

Fig. 9, Plate XXIII. repreſents Henley's Univerſal Diſcharger, which is a very uſeful inſtrument in a great variety of experiments. A is a flat board or pedeſtal about 15 inches long, 4 broad, and 1 thick. B, B, are two glaſs pillars, fixed faſt into the board A, and furniſhed at top with braſs caps, each of which has a vertical joint, and ſupports a ſpring-tube, through which the wire DC ſlides. Each of thoſe caps conſiſts of three pieces ſo connected

nected as that the wire D C, beſides its ſliding through the ſpring-ſocket, has two other motions, viz. an horizontal and a vertical one. Each of the wires D C, D C, is turned into a ring at one end, and at the other end has a braſs ball D, which, by means of a ſhort ſpring ſocket, is ſlipt upon its pointed extremity, and may be removed from it at pleaſure. E is a ſtrong piece of wood, or tablet, about 5 inches in diameter, having on its ſurface a ſlip of ivory inlaid, and is furniſhed with a ſtrong cylindrical foot that fits the cavity of the ſocket F, which is faſtened into the bottom board A, and has a ſcrew G, which ſerves to detain the foot of the circular tablet E at any required height. H is a ſmall preſs which belongs to this inſtrument. It conſiſts of two oblong pieces of board, which may be preſſed againſt each other, or againſt any thing that may be interpoſed, by means of the ſcrews and nuts *a*, *a*. The lower of thoſe boards has a cylindrical foot equal to that of the board E. When this preſs is to be uſed, it is fixed into the ſocket F, in the place of the circular board E, which muſt, in that caſe, be removed.

The inſtruments which either manifeſt the preſence, or manifeſt the preſence and the quality, or meaſure the quantity of electricity, are called *electrometers* or *electroſcopes*; and they have been made of a great variety of ſhapes, from which, as alſo from their uſes, they have derived peculiar appellations.

A ſimple thread, or a feather, or other light body, ſimply ſuſpended by a fine thread, may be uſed for exploring whether a body be electrified or not; for if the body be electrified, and be brought near it, the thread, or other light body, will be attracted by it.

The ſimpleſt electrometer for aſcertaining the quality as well as the preſence of electricity, has been already deſcribed; it is repreſented at fig. 2, and 3, Plate XXIII. and is called, from its inventor, *Canton's Electrometer.*

Fig. 10, Plate XXIII. repreſents *Henley's Quadrant Electrometer*, fixed upon a ſmall circular ſtand, from which it may be occaſionally ſeparated, and may be fixed upon the prime conductor, or elſewhere. This electrometer indicates the quantity, or rather the condenſation, of electricity. It conſiſts of a perpendicular ſtem of box wood, with a globular termination at top, and having a braſs ferrule at its lower extremity, by which it may be fixed upon the prime conductor, or upon the electrical battery, &c. To the upper part of the ſtem a graduated ivory ſemicircle is fixed, about the middle of which is a braſs arm, which contains a pin or axis of the index. The index conſiſts of a very ſlender ſtick of box wood, which reaches from the centre of the graduated ſemicircle to the braſs ferrule, and has a ſmall cork ball faſtened to its lower extremity. When this electrometer is not electrified, the index hangs parallel to the pillar, and its cork ball touches the braſs ferrule, as in fig.

fig. 10; but when electrified, the index is repelled by, or recedes from, the ſtem more or leſs, according to the intenſity of the electricity; and the graduation on the ivory ſemicircle ſhews the force or the elevation of the index, as at P in fig. 5.

A vaſt number of alterations have been made to this electrometer, viz. the index has been encloſed between two ivory ſemicircles; the whole has been made of braſs, with multiplying wheels, and a counterpoiſe has been put to the index, in order to render a ſmall force of electricity more perceptible, &c. but, after all, the ſimple original conſtruction, as deſcribed above, ſeems preferable.

The principle of Lane's Diſcharging Electrometer, as is now commonly uſed, eſpecially by the practitioners of medical electricity, is ſhewn in fig. 13, Plate XXIII. It conſiſts of a glaſs arm D, which proceeds from a ſocket on the wire of the electrical jar F, and to the top of which a braſs ſpring-ſocket E is cemented; through this ſocket a braſs wire, with the ball B at one end and the ring C at the other, may be ſlid backwards and forwards. The wire B C is generally marked with diviſions of inches and tenths. When the jar F is ſet in contact with the prime conductor, as repreſented in the figure, and the ball B is ſet at the diſtance, for inſtance, of one-tenth of an inch from the ball A, let a wire CK be fixed between the ring C of the electrometer, and the outſide coating of the jar; then, when the electrical machine is in action,

action, the jar F cannot be charged beyond a certain point; for when the charge is ſtrong enough to leap from the ball A to the ball B, the diſcharge will take place, and the ſhock will paſs through the wire C K, or through a human body, or through any other conducting body that is placed, inſtead of the wire C K, to form the communication. Thus by ſituating the ball B farther from the ball A, ſtronger ſhocks may be given, as far as the ſame jar is capable of.

This electrometer has likewiſe undergone a great many alterations. An improvement of it, and a combination of this and other electrometers was made by Mr. Cuthbertſon *.

In performing ſeveral atmoſpherico-electrical experiments about the year 1776, I found that the uſe of Canton's cork-ball electrometer was much obſtructed by the wind, in conſequence of which I attempted to encloſe it in a bottle, and after a variety of trials and alterations the inſtrument was in the year 1777 brought to the ſtate which is repreſented in fig. 11, Plate XXIII. which is about the half of the original ſize; but the ſhape as well as the ſize of it has been frequently altered by the philoſophical inſtrument makers. The three parts of the figure repreſent the inſtrument in its caſe, the ſame

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* See a deſcription of it in Nicholſon's Journal of Nat. Phil. &c. vol. II. p. 528.

out of the caſe, and a ſection of its braſs cap and neck.

CDMN is an open glaſs veſſel narrower at top than at bottom, and cemented into the wooden piece AB, by which part the inſtrument is held when it is to be preſented to the atmoſphere, or it may be reſted upon a table for other experiments. This wooden piece alſo ſerves to ſcrew the inſtrument into its wooden caſe O. The upper part of CDMN is tapering like the neck of a phial, and a ſhort glaſs tube is cemented into it, ſo as to project a little above and a little within the neck of the former, Then the upper part of the inſtrument, from CD to L, is covered with ſealing-wax, by means of heat, which gives it the appearance of one continuate body. The inner part G of the ſmall glaſs tube is alſo covered with ſealing-wax. Into this tube a braſs wire is cemented, the lower part H of which is flattened, and is perforated with two holes; the upper part L is formed into a ſcrew, upon which the braſs cap EF is ſcrewed. The office of this cap is to defend the upper part of the inſtrument from the rain. The conical, or oval, or globular, corks P of this electrometer, are as ſmall as can be made, and are ſuſpended by exceedingly fine ſilver wires, the upper parts of which are formed in rings, which paſs through the holes at H, and are thereby ſo looſely ſuſpended, that they are cauſed to diverge when the braſs cap E is expoſed to a very ſlightly electrified atmoſphere. IM and KN are

two

two narrow ſlips of tin-foil ſtuck to the inſide of the glaſs, and communicating with the wooden bottom A B;—they ſerve to carry off that electricity, which, when the corks touch the glaſs, is communicated to it, and if accumulated would diſturb the free motion of the corks.

An uſeful alteration of this electrometer was made by Mr. Bennet. It conſiſts of two ſlips of gold-leaf, or ſilver-leaf, ſuſpended from the cover of, and hanging within, a cylindrical glaſs veſſel, inſtead of the corks ſuſpended by wires or threads. The ſlips of gold are about 2 ½ inches long, and ſometimes they are narrower at their lower extremities. This electrometer is the moſt ſenſible inſtrument of the kind, and very uſeful in nice experiments; the gold ſlips being cauſed to diverge in a ready and unequivocal manner by very ſmall quantities of electricity; but the inſtrument, thus furniſhed, is by no means portable*. If very fine threads ſtiffened with glue, be uſed without any balls, they will be found nearly as ſenſible as the ſlips of gold leaf.

Such are the moſt eſſential parts of the electrical apparatus. But there is a great variety of particular inſtruments, which are to be uſed for the performance of peculiar experiments; but the deſcription of theſe, as well as the neceſſary inſtructions for the management of the ſame, and for the general performance of experiments, will be found in the ſequel.

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* See the deſcription of it in the Phil. Tranſ. vol. 77.

CHAP. VI.

ELECTRICAL EXPERIMENTS.

THE principal object of this chapter is, to deſcribe ſuch experiments as are more eſſentially neceſſary for proving the laws which have been ſtated in the preceding chapters of this ſection.

A few very trifling articles, ſuch as a glaſs tube, a ſtick of ſealing-wax, or a piece of amber, and two or three electrometers, will be ſufficient to prove the leading propoſitions of electricity; but the electrical machine being the principal article of a pretty large electrical apparatus, we ſhall begin by explaining the proper management of the ſame.

When the weather is clear and dry, eſpecially in ſerene and froſty weather, the electrical machine always works well. In very hot or damp weather, the machine does not work well; therefore more attention is required in the latter circumſtance than in the former; yet, with proper care, the electrical machine may at all times be made to work with ſufficient power, by attending to the following inſtructions.

Before the machine be uſed, the cylinder ſhould be wiped very clean and dry, and in cold weather it ſhould be gently warmed by keeping it a little while at a moderate diſtance from a common fire. This done, if the winch be turned, when all other things are removed, and the knuckle be held at a little diſtance from the ſurface of the cylinder, about the middle of it, and oppoſite to the rubber, the electric fluid will come from the cylinder to the knuckle, and the ſparks, accompanied with a crackling noiſe, will ſoon be perceived. But ſhould this not take place after about 20 or 30 turns of the cylinder, take off the rubber from its glaſs pillar, clean it well, and place it near the fire, in order to dry at leaſt the ſilk flap;—wipe the cylinder well with a warm flannel or warm ſilk handkerchief, and replace the rubber, ſo that it may bear upon the cylinder with ſufficient force; then hold the piece of leather with the amalgam againſt the cylinder at its under part while you turn the winch, and the machine will ſoon acquire its power. When this has taken place, remove the leather with the amalgam; place the prime conductor before the cylinder, as in fig. 4, Plate XXIII. wipe its ſtand NF quite clean and dry, and make a good communication, by means of a wire or otherwiſe, between the rubber and the ground; then turn the winch, and the electric fluid, in the form of ſparks, may be drawn from the prime conductor, by preſenting a blunt uninſulated conductor to its ſurface. The longeſt ſpark may be drawn from the knob O. If the point of a pin be preſented to the prime conductor whilſt the cylinder is revolving, a luminous globule of light will be ſeen upon the point, which is not attended with any noiſe. If the communication between the earth and the rubber be removed, and it be made between the earth and the prime conductor; then, on preſenting a pointed pin to the rubber, a bruſh or pencil of light will be ſeen iſſuing from the point, and tending towards the rubber.

If, when the communication is made between the earth and the prime conductor, a ſimple electrometer, viz. two cork balls faſtened at the ends of two threads, be ſuſpended to the knobbed wire MO; theſe will hang down touching each other, as long as the machine is not in action; but the leaſt turning of the cylinder will make them diverge, or fly from each other. If, in this ſtate of repulſion, you touch the prime conductor with an electric, as with a piece of glaſs, or ſealing-wax, or amber, or ſulphur, &c. the cork balls will continue to diverge; but if you touch it with any uninſulated conductor, ſuch as your finger, or a wire, or a piece of charcoal, &c. the threads with the balls will immediately collapſe. And this is a ready way of trying whether a given body be a conductor or not.

Now, according to the theory, the cylinder is enabled, by the friction, to draw the electric fluid, which naturally exiſted in the rubber, and throws it upon the prime conductor, from which, on account of of the inſulation, it cannot fly away, except what is communicated to the air, or what flies off in the form of ſparks to any conductor that may be preſented to the prime conductor.

If the rubber be inſulated, the electrical machine will loſe almoſt all its power, becauſe the rubber, after having ſupplied the cylinder with its own fluid, cannot receive any more, except a very little quantity of it from the ſurrounding air, which is ſeldom, if ever, a perfect electric.—The influx of electric fluid to the rubber, and the efflux from the prime conductor, is ſhewn by the luminous pencil or ſtar, which is ſeen on the pin or pointed conductor that is preſented to them.

If, when the cork balls are diverging at the end of the prime conductor, as mentioned above, you preſent to them an excited glaſs tube, or any other body poſitively electrified, the balls will fly from it; but they will run towards an excited piece of ſealing-wax, or towards any other body negatively electrified; and this is a ready way of trying whether an electrified body be poſitive or negative.

Sometimes another prime conductor is placed in contact with the rubber R I; then the communication being made between the prime conductor ML and the earth, the above-mentioned experiments may be made with the other prime conductor, but with this difference, that in the latter caſe they are affected by negative electricity, and ſhew ſigns of that electricity: hence, this conductor is called the

the *negative*, and ML is called the *poſitive*, *conductor*.

The flying feather.

Take an excited glaſs tube in one of your hands, and let a ſmall light feather be left in the air, at the diſtance of about 8 or 10 inches from the tube. This feather will be immediately attracted by the tube, and will adhere very cloſely to its ſurface during a few ſeconds, and ſometimes longer; then, having acquired the ſame ſort of electricity, it will be repelled, and by keeping the tube under it, the feather will continue to float in the air at a conſiderable diſtance from the tube, without coming near it again, except it firſt touches ſome conducting ſubſtance, upon which it can depoſit the acquired electricity. By managing the tube dexterouſly you may drive the feather to any part of the room at pleaſure.

A remarkable circumſtance attends this experiment, which is, that while you keep the feather from the tube, and move the latter about the former, the feather always preſents the ſame part towards the tube; the reaſon of which is, that when the equilibrium of the electric fluid amongſt the parts of the feather is once diſturbed, it is not eaſily reſtored, on account of the feather being a very bad conductor.

The electric well.

Place upon an inſulating ſtand, (viz. a ſtool with glaſs legs) a metal pint or quart mug, or ſome other

other conducting body nearly of the ſame ſhape; then faſten a ſhort cork-ball electrometer, like that of fig. 2, at the end of a ſilk thread, proceeding from the ceiling of the room, or from any other proper ſupport, ſo that the electrometer may be ſuſpended entirely within the mug. This done, electrify the mug, by giving it a ſpark with an excited electric, or otherwiſe, and you will find that the electrometer, whilſt it remains in that inſulated ſituation, and even if it be cauſed to touch the inſide ſurface of the mug, will not be attracted by it, nor will it acquire any electricity; but if a conductor, partly ſtanding out of the mug, be made to communicate with the electrometer, then the latter will be immediately attracted by the mug.

In this experiment the electrometer is acted upon from all ſides by the electricity of the mug, and having no body upon which it can depoſit its electric fluid, or acquire any from, cannot acquire the contrary electricity, and of courſe cannot be attracted; but when another conductor is preſented to it, then the attraction takes place, becauſe the electrometer in that caſe acquires ſome electric fluid from, or can depoſit its fluid upon, that conductor.

To ſhew the action of electric atmoſpheres.

Let a body be electrified, for inſtance, poſitively, and if at ſome diſtance from it you hold an electrometer of cork balls, this electrometer will be found to to diverge, but with negative electricity; which may be eaſily proved; for if you preſent to it an excited piece of glaſs, the cork balls will run towards it; but they will fly away from excited ſealing wax, ſuppoſing this to be excited always negatively, and the glaſs always poſitively.

Inſulate in an horizontal poſition a metallic rod with blunt terminations, as A B, fig. 14, Plate XXIII. about two feet long and having a cork-ball electrometer at its extremity A; then bring within 8 or 10 inches of its other end B an excited glaſs tube; and the balls C will immediately diverge with the ſame, viz. with poſitive electricity. If the tube be removed, the balls will immediately come together, and no electricity will remain in them or in the rod. But if, while the tube is near one end B of the rod, and the cork balls diverge with poſitive electricity, the other end A be touched with a finger, or with any uninſulated conductor, the cork balls will immediately collapſe, remaining as if the rod were perfectly unelectrified; but if, in this ſtate of things, the excited tube be removed, the balls will immediately diverge with negative electricity, ſhewing that the rod A B is undercharged.

This experiment is eaſily explained; for when the rod is in a natural ſtate with reſpect to electricity, then the electric fluid naturally belonging to it, is equably diffuſed throughout the rod; but when the excited tube is brought within a certain diſtance of one

one of its ends, as B, then the fluid belonging to that end will be driven towards the extremity A; which extremity therefore becomes overcharged, and the other extremity B undercharged, yet the rod has no more electric fluid now than it had before; and when the tube is removed beyond the ſphere of its action, the ſuperfluous fluid of the extremity A returns to its former place B, and the equilibrium is reſtored. But if, whilſt the extremity A is overcharged, this ſame extremity be touched, then its ſuperfluous fluid will be conducted away by the touching body, leaving the extremity A in a natural ſtate; but at the ſame time the extremity B is undercharged; therefore, when afterwards the tube is removed, part of the fluid naturally belonging to the extremity A, goes towards B, and of courſe the whole rod will remain undercharged, or electrified negatively.

This experiment, which may be endleſsly diverſified, and ſo ſimplified as to be performed with a ſimple cork-ball electrometer, ſhews how an electrometer or other body may be electrified negatively by means of a body electrified poſitively, or *vice verſa.*

To ſhew the alternate attraction and repulſion of the ſame light bodies.

Place upon a flat metallic plate any ſmall bodies, ſuch as pieces, or ſmall figures, of paper, or bits of gold-

gold-leaf, bran, &c. and whilſt the machine is in action, hold the ſaid plate directly under the prime conductor at about 3 or 4 inches diſtance from its ſurface; and the light bodies will ſoon move between the plate and the conductor, leaping alternately from the one to the other. In this experiment the ſmall bodies and the plate, by being within the ſphere of action of the electrified prime conductor, become actually poſſeſſed of the contrary electricity, leaving their electric fluid upon the hand of the operator, or other body that communicates with the plate: hence the light bodies (on account of the attraction between bodies differently electrified) are attracted by the prime conductor. Now as ſoon as theſe bodies touch the prime conductor, they become inſtantly poſſeſſed of the ſame electricity with it; therefore they are repelled (on account of the repulſion between bodies poſſeſſed of the ſame ſort of electricity), but they are attracted by the plate, which is in a contrary ſtate, &c.

If the conductor be ſuppoſed to be electrified negatively, the explanation requires a very trifling and very obvious alteration of expreſſions.

That the ſmall light bodies cannot be attracted by the conductor, unleſs they become firſt poſſeſſed of the contrary electricity, may be proved in the following manner: — Place the ſaid light bodies upon a clean and dry pane of glaſs, inſtead of the metalic plate, and holding the glaſs by one corner, place it under the electrified prime conductor. It will be found that the ſmall bodies are not attracted, becauſe in this caſe they have no opportunity of parting with their natural electric fluid, and conſequently cannot acquire the contrary electricity. But if a finger or any other conductor be preſented to the under ſide of the pane of glaſs, then the light bodies will be inſtantly attracted, repelled, &c. for theſe bodies can now depoſit their electric fluid upon the upper ſurface of the glaſs plate, whilſt the under ſurface of the glaſs depoſits its fluid upon the finger, or other conductor. If this experiment be continued, the pane of glaſs will ſoon be charged*.

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* The preceding experiments ſhew the following facts, or laws, which we ſhall aſſume as axioms, to prove that the repulſion of bodies poſſeſſed of the ſame ſort of electricity, be it poſitive or negative, ſeems to be clearly explicable on the theory of a ſingle electric fluid.

1. A body poſſeſſed of either ſort of electricity will induce, or tend to induce, the contrary electricity on any other body that comes within its ſphere of action, viz. within a certain diſtance of its ſurface.

2. A body cannot appear electrified on any part of its ſurface (meaning that the electrical power cannot manifeſt itſelf, or, according to the theory, the electric fluid cannot be equably diffuſed through it,) unleſs that ſurface is oppoſite to ſome other body which is actually poſſeſſed of the contrary electricity. And thoſe two contrarily electrified bodies attract or tend to attract each other.

Experiments with the Leyden Phial.

Place a coated jar, ſuch as that of fig. 7, upon the table where the electrical machine ſtands, and with

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3. According to the Franklinian hypotheſis, the electric fluid is elaſtic, that is, repulſive of its own particles, but attractive of the particles of other matter.

Now let A and B, fig. 15, Plate XXIII. be two ſpheres of conducting matter ſuſpended in the open air, contiguous to each other, and capable of being eaſily moved. Let ſome electricity be communicated to them, and it is evident that this electricity cannot be diffuſed equably over their ſurfaces, but it muſt be thicker or more condenſed on the parts that are remote from the point of contact, becauſe there the air is at liberty to acquire the contrary electricity; whereas near the point of contact, the electricity cannot be manifeſted, becauſe in that place there is no air or other body which can acquire the contrary electricity. Therefore the atmoſpheres of contrary electricities cannot be concentric with the ſpheres A and B, but muſt be ſituated ſomewhat like the dotted repreſentation of fig. 15; then the ſpherical bodies being attracted towards the centres of thoſe ſpheres, appear to repel each other, as ſhewn in fig. 16; ſo that when the bodies are electrified poſitively, negative atmoſpheres will be formed round them, and the additional electric fluid of the bodies will attract, and be attracted by, thoſe negative atmoſpheres. When the bodies are electrified negatively, poſitive atmoſpheres will be formed round them, which attract the undercharged bodies.

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with its knob A, in contact with the prime conductor, alſo place Henley's quadrant electrometer upon the prime conductor; then work the machine, and the index of the electrometer will riſe gradually as far as a certain height, which depends upon the force of the machine, ſize of the jar, &c. beyond which it will not riſe. You may then conclude that the jar has received its full charge *. Take a diſcharging rod, and, holding it by its glaſs handle, apply one of its knobs to the outſide coating of the jar, then bring its other branch towards the knob A

This explanation may be eaſily applied to bodies of any other ſhape; proper allowance being made for their more or leſs perfect conducting or nonconducting nature.

* Some ſort of glaſs is more apt to diſcharge itſelf over its ſurface than others. A battery cannot in general be charged ſo high as a ſingle jar. The dampneſs or dryneſs of the air does alſo influence the charge. Yet Mr. Cuthbertſon found, that by breathing into a jar through a glaſs tube, previous to the charge, the jar will be enabled to hold a much greater charge. He judges of the force of a battery or jar by the length of wire which its diſcharge is able to fuſe. Thus ſpeaking of his experiments with a certain battery, he ſays, "This battery contained 17 ſquare feet of coated glaſs, and was compoſed of 15 jars; it was found in the then ſtate of the atmoſphere to be incapable of fuſing a greater length of wire than 18 inches. But after breathing into each jar through a glaſs tube, it took a charge which fuſed 60 inches." Nicholſon's Journal of Nat. Phil. &c. vol. II. p. 527.

of the jar, and you will hear a report, and will ſee vivid ſparks between the diſcharging rod and the conducting ſubſtances that communicate with the ſides of the glaſs. This operation diſcharges the jar. If, inſtead of uſing the diſcharging rod, you touch the outſide of the jar with one hand, and its knob with the other hand; then, beſides the report, &c. you will feel a peculiar ſhock, which, according to the height of the charge, ſize of the jar, &c. will affect either your wriſts, or elbows, or breaſt, &c. If a number of perſons join hands, and the firſt of them touches the outſide of the jar, and the laſt touches the knob, they will all feel the ſhock, and preciſely at the ſame perceivable inſtant. But thoſe who are nearer to the coatings of the jar, or who are at the extremities of the circuit of communication, will feel the ſhock ſtronger than the reſt; for the electricity of either ſide becomes leſs condenſed, and of courſe leſs active in proportion as it expands itſelf through a greater quantity of conducting matter.

The force of the diſcharge may be manifeſted by a great variety of experiments.—Take a card or quire of paper, or two cards kept a little aſunder by the interpoſition of little bits of wax here and there; place either of thoſe articles flat againſt the outſide coating of a charged jar, and put one of the knobs of the diſcharging rod over it, ſo that the card or quire of paper, or the two cards, may be interpoſed between that knob and the coating of the jar;

jar; then, by bringing the other knob of the diſcharging rod near the wire of the jar, make the diſcharge; and the electric matter, ruſhing through the circuit from the poſitive to the negative ſide of the jar, will pierce a hole, and frequently more than one hole, quite through the card or cards, or quire of paper, &c.; and each hole will be found to have a bur raiſed on each ſide, unleſs the card be preſſed too hard againſt the ſide of the jar*. If the noſtrils be immediately preſented to ſuch perforation, a ſmell, ſomewhat like that of phoſphorus, will be perceived. If, inſtead of paper, a very thin plate of glaſs, or of roſin, or of ſealing-wax, be interpoſed between the diſcharging rod and the outſide coating of the jar, on making the diſcharge, this will be broken in ſeveral pieces.

If a piece of white ſugar be interpoſed, and the ſhock be ſufficiently ſtrong, the ſugar will be broken, and in the dark it will appear beautifully illuminated, remaining ſo for nearly a minute after.

Put the extremities of two wires upon the ſurface of a card, or, which is the ſame, place the card flat upon the tablet E of the univerſal diſcharger, fig. 9, and having removed the knobs D, D, incline the wires, ſo that their extremities may reſt upon the card, and at about an inch diſtance

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* This ſhews, that the bur and the perforation are made by the expanſion of the ſubſtance of the card or paper.

from each other; then, by connecting one of the rings, or wires C, with the outſide of a charged jar, and the other wire C with the knob of the jar, the ſhock will be cauſed to paſs over the card; and after the ſame manner it may be cauſed to paſs over the ſurface of any other body.

If the card be very dry, the diſcharge will leave upon the card between the extremities of the two wires a lucid track, which will remain upon it during ſome ſeconds. If the ſhock be paſſed over a piece of writing paper, this will be torn into very ſmall bits. If the ſhock be ſent over a piece of glaſs plate, the ſurface of the glaſs will thereby be marked with an indelible track. In this experiment the glaſs plate is ſeldom broken; but Mr Henly found that it may be eaſily broken if weights have been previouſly laid upon it. He uſed to place a thick piece of ivory upon that part of the glaſs which ſtood between the extremities of the wires, and upon that ivory he placed any weight from a quarter of an ounce to ſix pounds. On making the diſcharge, the glaſs would generally be broken into innumerable pieces, ſome of it being abſolutely reduced into an impalpable powder. If the glaſs be too thick to be broken by the force of the exploſion, it will be found marked with the moſt lively priſmatic colours, which are occaſioned by very thin laminæ of the glaſs, partly ſeparated by the ſhock. The weight is always ſhook by the exploſion,

ploſion, and ſometimes it is quite thrown off from the ivory.

If the card, over which the ſhock is ſent, be painted with any particular colour, a permanent black mark is generally left upon it, eſpecially if it be painted with vermillion *.

In order to fire gun-powder by means of the Leyden phial, make a ſmall cartridge of paper, and fill it with gun-powder, or elſe fill the tube of a quill with it, and inſert the pointed extremities of two wires in it, ſo that their extremities within the powder may be about one-fifth part of an inch from each other. This done, ſend the charge of a Leyden phial through thoſe wires, and the gun-powder will be fired. If the powder be mixed with ſteel filings, the experiment will ſucceed even with a ſmall ſhock.

If the gun-powder be placed looſely upon any ſtand, and the interruption of the wire circuit be made in it; on making the diſcharge of the jar, the ſpark which takes place at that interruption, will ſcatter the gun-powder without firing it. But the looſe gun-powder may be fired, if the ſhock be tranſmitted through leſs perfect conductors; in which caſe the diſcharge being leſs ſudden, or rather proceeding in a ſtream, the powder will be fired.

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* See my Treatiſe on Electricity, 4th edition, vol. II. page 59.

The beſt method of peforming this experiment is ſhewn in fig. 12, Plate XXIII.

F is the gun-powder, placed upon the ſame table upon which the jar A B is ſituated; C D is a glaſs tube about one foot long and a quarter of an inch in diameter, full of water, and having two corks at its extremities. Into theſe corks two wires are thruſt, the inner extremities of which juſt touch the water, viz. the ſhort wire at D, and the long wire C A, which makes the communication between the water of the tube and the knob of the jar. On making the diſcharge, which muſt paſs through the ſmall quantity of water in C D, and through the table F B, both imperfect conductors, the electric fluid comes out at D, in the form of a denſe ſtream, which generally fires the gun-powder at F.

If a ſpoon, containing ſpirit of wine, be connected with the outſide of a Leyden phial, and the knob of a wire, communicating with the inſide of the phial, be brought juſt over the ſurface of the ſpirit, at a ſmall diſtance from it, the diſcharge of the phial will ſet fire to the ſpirit of wine, provided this has been previouſly warmed. But the ſame thing may be done by paſſing a ſimple ſpark from the prime conductor of the machine through the warmed ſpirit of wine.

A very fine ſlender wire may be fuſed by the diſcharge of a ſingle jar. For this purpoſe you need only make that wire part of the circuit; for inſtance,

inſtance, place it between the extremities of the wires of the univerſal diſcharger. The fine turnings or ſhavings of ſteel, which may be had at the philoſophical inſtrument makers, are very eaſily fuſed, even by a ſmall ſhock. But a wire of the 50th part of an inch or upwards, requires a conſiderable battery to melt it *.

Take two ſlips of common window-glaſs, about three inches long and half an inch broad; put a ſmall ſlip of gold, or ſilver, or braſs-leaf between them, leaving a little of the metallic leaf out of the glaſſes at the two ends, and place thoſe glaſs ſlips between the boards of the preſs H of the univerſal diſcharger, fig. 9, which preſs muſt be put in the place of the tablet E; then by connecting the wires D, D, with the projecting extremities of the metallic leaf, &c. ſend the charge of a pretty large jar through it; the conſequence will be that the glaſſes

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* It appears that the higheſt charge of a battery, belonging to Dr. Van Marum, and containing 135 ſquare feet of coated ſurface, could juſt fuſe 180 inches of iron wire, $\frac{1}{150}$ of an inch in diameter, or 6 inches of iron wire, $\frac{1}{40}$ of an inch in diameter; another battery belonging to the ſame perſon, and containing 225 ſquare feet of coated ſurface, could melt, with its higheſt charge, 300 inches of the firſt-mentioned wire, or 10 inches of the laſt; alſo the higheſt charge of a third battery, which contained 550 ſquare feet of coated ſurface, could fuſe 25 inches of the latter wire. Nicholſon's Journal of Natural Philoſophy, &c. vol. II. page 527.

are

are generally ſhattered by it; but whether they are broken or not, they will be found indelibly marked by the metal, which is forced ſo far into the pores of the glaſs, as not to be affected even by the menſtrua which otherwiſe are wont to diſſolve it.

Take a wire of the ſize of a common knitting-needle, or larger, and by means of any eaſily flexible wire or chain, let one end of it communicate with the outſide coating of a jar, that contains at leaſt ten ſquare inches of coated ſurface. Round the other end of the firſt-mentioned wire, ſome cotton muſt be looſely twiſted, ſo as to form a head round it, and thus conceal the end of the wire. Roll this head of cotton in powder of lycopodium, or in powder of roſin: this done, charge the jar, and bring the cotton head rather quickly towards its knob; by which means the diſcharge will be cauſed to paſs through the ſaid cotton, which will thereby be inſtantly ſet on fire.

If a jar be diſcharged with a diſcharging rod that has not an electric handle, the hand which holds the rod, on making the diſcharge, feels a partial ſhock. In other words, a perſon, or any conducting ſubſtance that is connected with one ſide of a Leyden phial, but that forms no part of the circuit, will feel a kind of ſhock, or ſome effect of the diſcharge. Thus, if you connect a piece of a chain with the outſide of a jar, or place it very near the jar; then diſcharge the jar through another circuit, as for inſtance, by means of a common diſcharging rod;

on making the diſcharge in the dark, ſparks will be ſeen between the links of the chain, alſo between the chain and the jar; which ſhews that the electric fluid of the chain is affected by the proximity of the jar. If this chain be inſulated, it will be found, after the diſcharge of the jar, not to be electrified: hence Dr. Prieſtley (who firſt deſcribed this effect out of the circuit, and to which he gave the name of *lateral exploſion)* thinks that this lateral ſpark flies from the coating of the jar to the chain, and inſtantly returns to the former.

Thus far I have deſcribed ſuch experiments as ſhew the effects or the power of charged electrics, and which may be moſtly performed with a ſingle jar. That power may be ſhewn in a much more ſurpriſing manner by the uſe of a large battery; but the management of ſuch battery being ſimilar to that of a ſingle jar, it is needleſs to give any particular directions reſpecting the uſe of the ſame. We may only obſerve, by way of precaution, that more care and attention is required in the management of a large battery, leſt the ſhock, which might be very hurtful, ſhould unexpectedly paſs through the operator, or any of the by-ſtanders.

After having diſcharged a large battery, the operator ſhould once more apply the diſcharging rod to the outſide and inſide coatings of the battery; for a reſiduum of the charge generally remains in it after the firſt diſcharge, which might afterwards give an unexpected

unexpected ſhock. The ſame precaution may be extended to a ſingle large jar.

I ſhall now add ſuch experiments as may illuſtrate the theory of the Leyden phial, and the hypotheſis of a ſingle electric fluid.

Place a coated jar on an inſulating ſtool, and with its knob, not in contact, but within an inch of the prime conductor; then work the machine, and after a certain time you will find, upon trial, that the jar is not charged, becauſe its outſide, being inſulated, could not part with its electric fluid, and of courſe its inſide could not receive any additional quantity of it. But if you hold the knob of a wire at ſuch a diſtance from the outſide coating of the jar, as the knob of the jar is from the prime conductor; then, on working the machine, you will find, that whenever a ſpark goes from the prime conductor to the wire of the jar, another ſpark paſſes from the outſide coating of the jar to the knob of the wire that is preſented to it; which ſhews that according as a quantity of electric fluid enters the jar, about an equal quantity of the electric fluid which belongs to the outſide of the jar, leaves that outſide. In this manner the jar becomes charged. If in this experiment the ſame fluid which goes from the prime conductor to the knob of the jar, came through it, and paſſed to the oppoſed knob, the jar could not poſſibly become charged.

When the jar is charged, if you preſent the pointed extremities of the diſcharging rod at a certain

certain diſtance from the outſide coating and from the knob of the jar, as ſhewn in fig. 7, you will perceive (if the experiment be performed in the dark) both points illuminated, viz. the upper point with a little ſtar, and the lower, B, with a bruſh of light, provided the jar has been charged poſitively in the inſide; but if the jar be charged negatively in the inſide, (viz. by preſenting its knob to the negative conductor) then the ſtar and the bruſh will be reverſed, viz. the bruſh will iſſue from the upper, and the ſtar will appear on the lower, point. By this means the jar is ſilently diſcharged.

Diſpoſe the apparatus as in the above-mentioned experiment, (p. 408) with the card; viz. lay a card upon the tablet E of the univerſal diſcharger, fig. 9, but with this difference, that inſtead of laying the extremities of both wires upon the ſame ſide of the card, one of them be placed under the card; then ſend a ſhock through the ſaid wires, as in the above-mentioned experiment, and it will be found that the electric fluid will run over that ſurface of the card, upon which ſtands the wire that communicates with the poſitive ſide of the jar; and in order to paſs to the other wire, it will break a hole through the card juſt over the extremity of that other wire. Thus let A B, fig. 17, Plate XXIII. repreſent a ſection of the card; C and D the extremities of the wires laid upon the oppoſite ſurfaces of the card; then, if the wire D be connected with the poſitive ſide of the jar, on making the diſcharge the electric fluid

fluid will run over the card from D to E, and at E it will break a hole and paſs to the wire C, which communicates with the negative ſide of the jar; but if the wire C be connected with the poſitive ſide of the jar, then, on making the diſcharge, the electric fluid will run along the ſurface of the card from C to F, and at F it will break a hole and paſs to the wire D.

The courſe of the electric fluid in this experiment may be ſeen either by the luminous track, if the experiment be performed in the dark, or by previouſly painting the card on both ſides with vermillion and gum-water; for the paſſage of the electric fluid will leave a permanent dark track upon it.

Take a ſmall coated phial, and by breathing upon its external uncoated part, render that part ſlightly damp; then holding it by its outſide, preſent its knob to the prime conductor, while the machine is in action, and you will find that, after the phial has received a ſmall charge, a beautiful bruſh of rays will proceed from the cork, which, after going a little way into the air, bends its courſe towards the outſide coating of the phial. If the phial be charged negatively in the inſide (viz. if its knob be preſented to the inſulated rubber), then the luminous bruſh will iſſue from the outſide coating, and will proceed towards the cork or wire of the phial. In this experiment the outſide of the phial muſt be damped to a certain degree, which experience only can teach.

Remove the circular board E from the univerſal diſcharger, fig. 9; fix the wires D C, D C, ſo that their knobs D, D, may be about two inches aſunder, and upon the ſocket F fix a piece of wax-taper lighted, ſo that its flame may be midway between the two knobs D, D. This done, if you connect, by means of a chain or otherwiſe, the outſide of a charged Leyden phial with one of the wires C, and bring the knob of the phial to the other wire C, you will obſerve that on making the diſcharge, which muſt paſs from one of the knobs D to the other, the flame of the wax-taper is always driven in the direction of the electric fluid; that is, it will be blown upon the knob of that wire which communicates with the negative ſide of the phial.

In this experiment the phial muſt have a ſmall charge, which experience will preſently determine. With high charges the experiment does not ſucceed, becauſe the charge paſſes too ſuddenly, and likewiſe becauſe on approaching the phial to the wire, a conſiderable electrical atmoſphere is formed round the knob of that wire, which diſturbs the flame, &c.

If a Leyden phial be cloſely ſtopped, and a narrow and open tube, containing a drop of water, be paſſed through and cemented into its cork, it is evident that if the air within the jar be at all rarefied

or

or condenſed, the drop of water within the tube muſt be moved from its place. Now on charging this phial either poſitively or negatively in the inſide, the water within the narrow tube will not be moved from its place; which ſhews that the charge does by no means diſplace the air. Nor will the water be moved on making the diſcharge, unleſs a ſpark happens between the inſide coating and the wire, or between the various parts of the inſide coating; for a ſpark always rarefies a little and diſplaces the air.

Take a naked phial, and for a coating on the outſide ſtick a piece of tin-foil with a little wax, ſo that it may juſt adhere to the glaſs; and for an inſide coating uſe ſmall leaden ſhot, or quickſilver; laſtly, inſert a wire into the phial. This done, hold the phial, thus coated, by its outſide, and charge it in the uſual manner. When charged, turn it upſide down, and pour its contents into an inſulated cup for examination; alſo remove the outſide coating. By this operation the phial does not loſe its charge, and if the quickſilver or the ſhot which formed the inſide coating be examined by means of an electrometer, it will be found ſlightly electrified, viz. as much as any other like inſulated conductor that has been in contact with the prime conductor. Pour the ſame ſhot or quickſilver, or elſe ſome other quickſilver again into the phial, and replace the outſide coating; then touch the outſide coating with one hand, and the inſide with the other hand, by means of a wire, &c. and you will feel a ſhock, which will convince you that the phial had not loſt its charge, and will at the ſame time prove that the charge does not reſide in the coating.

The illuſtration which the preceding experiments afford to the theory of a ſingle electric fluid is ſo obvious as to require no farther explanation. A vaſt number of other experiments with the Leyden phial might now be added, which, however, are in general only variations of thoſe which we have already deſcribed. The inquiſitive reader may find abundance of ſuch experiments deſcribed by the numerous writers on electricity.

CHAP. VII.

OF THE VARIOUS SOURCES OF ELECTRICITY.

HITHERTO we have taken notice of one mode of producing electricity, namely, by means of friction; and have ſtated its properties, together with its moſt rational theory. But electricity is alſo produced by other means, which remain to be deſcribed, and which indeed are intimately concerned in ſeveral grand natural proceſſes.

There is hardly an operation of nature which does not produce ſome electricity, or with which electricity does not ſeem to be in ſome meaſure concerned. Probably all the different productions of electricity follow one general law; however, for the ſake of perſpicuity it will be neceſſary to ſpecify thoſe various ſources, beſides friction, and to reduce them to the following ſpecies.

1. Electricity is produced by the melting or by the coagulation after liquefaction, of certain ſubſtances.

2. It is produced by merely heating or cooling ſome particular bodies.

3. It is produced by evaporation and by the condenſation of vapour.

4. It is to be found in the atmoſphere at all times more or leſs.

5. It is yielded by certain animals; and, laſtly,

6. It is produced by the mere contact, or by the natural action of certain conducting bodies upon each other.

We ſhall deſcribe thoſe different ſources of electricity in the following chapters; comprehending the firſt three under the title of *electricity produced by melting, heating, cooling, and evaporation*; the 4th under the title of *atmoſpherical electricity*; the 5th under the name of *animal electricity*; and the laſt under the appellation of *Galvaniſm*.

But previous to this it will be neceſſary to deſcribe, in the preſent chapter, the principal methods that have been contrived for diſcovering the preſence, and for aſcertaining the quality, of very ſmall quantities of electricity; for ſometimes the electricity, which is produced by the above-mentioned ſources, is ſo very ſmall as to require the utmoſt attention and mechanical contrivance on the part of the philoſopher.

The action of electric atmoſpheres is the principle which has furniſhed the methods of manifeſting the preſence of ſmall quantities of electricity, viz. of ſuch quantities as of themſelves could not affect an electrometer ſenſibly.

Let an electrometer be affixed to an inſulated metallic

metallic plate. Communicate ſome electricity to this plate, and the electrometer will diverge. In this ſtate bring the plate near a conductor not inſulated, and you will find that the electrometer collapſes in proportion as you approach the plate to the uninſulated conductor. Remove the electrified plate, and the electrometer will again diverge to its former degree very nearly; which ſhews that by the vicinity of the uninſulated conducting body, which could eaſily acquire the contrary electricity, the intenſity of the electricity in the electrified plate was diminiſhed; or, which is the ſame thing, that the capacity of that plate for containing electricity was increaſed, becauſe in that ſituation a greater quantity of electricity muſt be communicated to the plate, in order to raiſe the electrometer to the ſame height as when the plate is not oppoſed to an uninſulated conductor.

It eaſily follows, that according as the conductor which is oppoſed is larger or ſmaller, and alſo as it is nearer or farther, ſo the capacity of the plate may be increaſed more or leſs.

Now if there be a ſource of electricity which, when communicated to an electrometer, is too weak to affect it; let an ample inſulated plate be ſituated very near another plate not inſulated, and in that ſtate let the former plate communicate with the body which furniſhes the weak electricity; and the plate ſo ſituated will acquire a conſiderable quantity of that electricity, which, whilſt this plate is oppoſed to the other, will not affect the electrometer; but if afterwards the receiving plate be removed from the vicinity of the other plate, its capacity for containing electricity will be diminiſhed, and of courſe the abſorbed electricity will appear much ſtronger upon its ſurface, &c.—Such a receiving plate was called a *condenſer* by Mr. Volta.

Farther, it muſt be remarked that when a body is electrified, if an inſulated plate be brought near it, and in that ſtate be touched, for inſtance, with a finger, the plate will thereby acquire the contrary electricity. Now remove the finger, alſo remove the plate, and give its electricity to an inſulated body, as to an electrometer, by touching it with that plate; then repeat the operation, viz. bring the ſame plate near the original electrified body, and touch it, by which means you can communicate to it as much electricity as before, which may alſo be communicated to the ſame electrometer; and thus by degrees the electrometer will be cauſed to diverge ſufficiently; whereas the mere contact of the original electrified body might not be nearly ſufficient to affect it ſenſibly. In this caſe the electricity which is communicated to the electrometer is evidently contrary to that of the original electrified body; viz. it will be poſitive if that was negative, and *vice verſa*.

Upon this principle the electrophorus acts *;

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* See my Treatiſe on Electricity, 4th edition, vol. II. p. 49, and following; alſo p. 244, and following.

and upon this principle ſeveral machines have been contrived for rendering manifeſt a ſmall quantity of electricity *.

Before the year 1795, I contrived a machine for this purpoſe, to which, by way of diſtinction, I gave the name of *Multiplier of Electricity*, and which, after long uſe, ſeems (if the partiality for my own contrivance do not deceive me) to anſwer the purpoſe in a manner more commodious and much leſs equivocal than any other inſtrument of the kind. This machine is delineated in Plate XXIII. fig. 19, which is about one-third of the real ſize.

Q R S is the bottom board, upon which are ſteadily fixed on the glaſs ſticks H, G, two flat braſs plates, A and C. B is a ſimilar braſs plate ſupported by a glaſs ſtick I, which is cemented into a hole made in the wooden lever KL. This lever moves round a ſteady pin or axis K, which is ſcrewed tight in the bottom board. By moving this

lever

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* Mr. Bennet's Doubler is an ingenious contrivance for the purpoſe of manifeſting very ſmall quantities of electricity, which acts upon the above-mentioned principle. It was afterwards improved by Mr. Nicholſon. But in all its ſtates it is apt to contract a certain permanent electricity, which renders its effect equivocal in moſt caſes. See the Philoſophical Tranſactions, vol. 77 and 78; alſo my Treatiſe on Electricity, 4th edition, vol. III. p. 76, and following.

See Mr. Volta's Method in the Phil. Tranſ. vol. 72, or in my Treatiſe as above, vol. II. page 244, &c. See alſo vol. III. page 91, &c.

lever alternately from L to X, and back again, the plate B, with the lever, may be placed in the two ſituations, viz. the ſituation L I B K, and that which is ſhewn by the dotted repreſentation of the ſame. N is a thick braſs wire fixed tight into the bottom board. O*m* is a crooked wire that proceeds from the braſs ſocket on the back of the plate B.

There is likewiſe a fourth braſs plate D, ſimilar to the others, which is ſupported, not by glaſs, but by a wire; and this wire is ſcrewed faſt to an oblong piece of braſs F P, which ſlides in a groove made for the purpoſe in the bottom board Q R S; ſo that by applying a finger's nail to the notch at the end F, the ſliding piece F P may be drawn out either entirely or to a certain length, and of courſe the plate D will be removed to any required diſtance from the plate C. When F P is puſhed quite home, the plate D ſtands parallel to C, and at $\frac{1}{30}$th of an inch diſtance from it.

The parts of this inſtrument are ſo adjuſted, as that when the lever is in the ſituation of the ſhaded part of the figure, viz. is puſhed as far as it can go towards Q, then the plate B comes parallel to the plate A, and at about $\frac{1}{20}$th of an inch diſtance from it. At the ſame time the extremity of the wire O*m* juſt touches the fixed wire N, and of courſe renders the plate B uninſulated. But as ſoon as the lever begins to move towards S, the communication of the plate B with the wire N, or with the ground, is interrupted, and B remains inſulated. When the lever has been moved as far as it can go towards S, the wire *m* comes in contact with the plate C, as is ſhewn by the dotted part of the figure. Then the two plates B and C communicate with each other, but they are otherwiſe inſulated.

When this inſtrument is ſituated in the manner which is indicated by the ſhaded part of the figure, the plate A has its capacity for electricity increaſed by the proximity of the uninſulated plate B: hence A, if it be cauſed to touch a body weakly electrified, will acquire a greater quantity of electricity from it than it would otherwiſe do. Now ſuppoſe that A has acquired a ſmall quantity of electricity, for inſtance, poſitive (ſince by changing the words poſitive for negative, and *vice verſa*, the following explanation is applicable to the caſe in which A is electrified negatively); then B will acquire the negative electricity. On moving the lever L, the communication between B and the ground, or the wire N, is diſcontinued, and B remains inſulated and electrified negatively. With this electricity B is carried towards C, until the wire *m* touches the plate C, and then the negative electricity of B will paſs almoſt entirely to C, becauſe the capacity of C for holding electricity is conſiderably increaſed by the proximity of the uninſulated plate D. If after this the lever be moved back to its firſt ſituation, B will be made negative a ſecond time as before; and by puſhing the lever again towards S, that ſecond charge of negative electricity will be communicated from

from B to C. And thus by repeating the operation, which conſiſts in merely moving the lever alternately from L to X, and from X to L, a conſiderable quantity of electricity will be accumulated upon C. Then if the ſliding piece FP be drawn out about one inch, the plate D will, of courſe, be removed as much from C: hence the capacity of C will be much diminiſhed. Therefore, if an electrometer be brought into contact with it, the negative electricity, (viz. the electricity contrary to that of the original electrified body in queſtion), will be manifeſted; whereas the electricity originally communicated to the plate A could perhaps not have affected an electrometer in any ſenſible degree.

The principal cauſe which renders this inſtrument certain in its effects, is, that all the reſiduum of electricity which can remain upon the plate A after the performance of an experiment, and after having touched that plate, is too inconſiderable to induce a contrary electricity in B; the electricity which is originally communicated to A, being not increaſed upon it in the courſe of the experiment*.

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* For farther particulars relative to this inſtrument ſee my Treatiſe on Electricity, 4th edition, vol. III. page 98, and following.

CHAP. VIII.

OF THE ELECTRICITY WHICH IS PRODUCED BY MEANS OF MELTING, HEATING, COOLING, AND EVAPORATION.

IF ſulphur be melted in an earthen veſſel, and the whole be left to cool upon conductors; and if afterwards the ſulphur, when cold, be taken out of the veſſel, it will be found ſtrongly electrical; but not at all ſo if it be left to cool upon electrics.

If ſulphur be melted in a glaſs veſſel, and be left to cool, both the glaſs and the ſulphur will acquire a ſtrong electricity; the former poſitive and the latter negative; and that will be the caſe whether they be left to cool upon electrics or upon conductors.

If melted ſulphur be poured into a veſſel of baked wood, it will acquire the negative, and the wood the poſitive, electricity; but if it be poured into ſulphur, or rough glaſs, it will acquire no ſenſible degree of electricity.

Melted ſulphur poured into a metal cup, and there left to cool, ſhews no ſigns of electricity whilſt ſtanding in the cup; but if they be ſeparated, then they will both appear ſtrongly electrified, the ſulphur poſitive, and the cup negative. If the ſulphur be replaced in the cup, every ſign of electricity will vaniſh; but if, whilſt ſeparate, the electricity either of the cup or of the ſulphur be taken off; then on being replaced they both will appear poſſeſſed of that electricity which has not been taken off.

Melted wax, being poured into glaſs or wood, acquires the negative electricity, and the glaſs or wood becomes poſitive. But ſealing-wax, poured into a ſulphur veſſel, acquires the poſitive electricity, and leaves the ſulphur negative.

Chocolate freſh from the mill, as it cools in the tin pans in which it is received, becomes ſtrongly electrical. When turned out of the pans, it retains this property during a certain time, but loſes it preſently by handling. By melting it again in an iron ladle, and pouring it into the tin pans as at firſt, you may renew its power once or twice; but when the maſs becomes very dry and powdery in the ladle, the electricity is no longer revived by ſimple melting; but if then a little olive oil be added, and be mixed well with the chocolate in the ladle, and be afterwards poured into the tin pans, as at firſt, it will be found to have completely

recovered

recovered its electrical power, which continues a conſiderable time *.

The property of becoming electrified merely by heating or cooling, was firſt obſerved in, and is eminently poſſeſſed by, an hard pellucid ſtone called *tourmalin*, which is generally of a deep red, or purple, or brown colour; which ſeldom, if ever, exceeds the ſize of a ſmall walnut; and which is found in ſeveral parts of the Eaſt Indies, eſpecially in the iſland of Ceylon; but on farther examination it has been found that ſeveral other precious ſtones, and eſpecially the Braſilian emerald, poſſeſs the like properties more or leſs: hence the following particulars, which have been principally obſerved with the tourmalin, muſt be underſtood to belong likewiſe to moſt other precious ſtones.

1. The tourmalin, while kept in the ſame temperature, ſhews no ſigns of electricity; but it will become

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* Reſinous or oleaginous electrics, when once excited, retain their electric power for a very conſiderable time, ſometimes for ſeveral days. But that power gradually diminiſhes, and at laſt vaniſhes; nor do we know of any electric which retains the electric virtue as permanently as the magnet retains its magnetic power.

When a ſtick of glaſs, or of ſulphur, and eſpecially of ſealing-wax, is broken into two pieces, the extremities which were contiguous, will generally be found electrified, one poſitive and the other negative. This is probably occaſioned by the ruſhing in of the air, which may produce a ſlight friction.

become electrical by increaſing or diminiſhing its heat, and ſtronger in the latter circumſtance than in the former. A very trifling alteration of temperature is often ſufficient to produce the effect.

2. Its electricity does not appear all over its ſurface, but only on two oppoſite ſides of it, which may be called its poles, and which always are in one right line with the centre of the ſtone, and in the direction of its ſtrata; in which direction the ſtone is abſolutely opaque, though in the other it is ſemitranſparent.

3. Whilſt the tourmalin is heating, one of its ſides (call it A) is electrified plus, or poſitive, and the other, B, minus; but when cooling, A is minus, and B is plus. Hence, if one ſide of the ſtone is heating, whilſt the other is cooling, then both ſides will acquire the ſame electricity; or if one ſide only changes its temperature, then that ſide only will appear electrified.

4. If this ſtone be heated, and ſuffered to cool without either of its ſides being touched, then A will appear poſitive, and B negative, all the time of its heating and cooling.

5. This ſtone may be excited by means of friction like any other electric, and either of its ſides, or both, may be rendered poſitive.

6. If the tourmalin be heated or cooled upon ſome other inſulated body, that body will be found electrified as well as the ſtone; but it will be found poſſeſſed

poſſeſſed of the electricity contrary to that of the contiguous ſide of the ſtone.

7. The electricity of either ſide, or of both, may be reverſed by heating or cooling the tourmalin in contact with various ſubſtances, ſuch as the palm of the hand, a piece of metal, &c.

8. Thoſe properties of the tourmalin are alſo obſervable in vacuo, but not ſo ſtrong as in the open air.

9. If a tourmalin be cut into ſeveral parts, each piece will have its poſitive and negative poles, correſponding to the poſitive and negative ſides of the original ſtone.

10. If this ſtone be covered all over with ſome electric ſubſtance, ſuch as ſealing-wax, oil, &c. it will in general ſhew the ſame properties as without it.

11. A vivid light appears upon the tourmalin, whilſt heating in the dark, and by a little attention one may be eaſily enabled by this light to diſtinguiſh which ſide of the ſtone is poſitive, and which negative. Sometimes, when the ſtone is ſtrongly excited, pretty ſtrong flaſhes may be ſeen in the dark, to go from the poſitive to the negative ſide of it.

12. Laſtly, it has been found that with reſpect to the electric properties, the tourmalin is ſometimes injured by the action of a ſtrong fire, at other times is improved, and ſometimes is not at all altered by it.

The

The evaporation of water, as alſo of ſome other fluids, produces electricity, viz. thoſe bodies from which the water has departed, will remain in a negative ſtate of electricity, indicating that the water by its converſion into vapour has its capacity for the electric fluid increaſed, as it has its capacity increaſed for containing heat*. But though the effect is in general ſuch as has been mentioned above, yet there are two exceptions which involve the ſubject in ſome difficulty, and which will require farther experiments and conſideration.

The exceptions are, 1ſt, that if water be evaporated by being put in contact with a red-hot piece or pieces of very ruſty iron, it will leave the iron electrified poſitively; whereas, if the iron be not ruſty, the evaporation of the water from its ſurface will leave it electrified negatively †. 2dly, If water be evaporated by throwing into it impure red-hot glaſs (ſuch as the green glaſs of common bottles) the veſſel, or the remaining water, will be electrified poſitively ‡.

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* Mr. Volta, who made this remarkable diſcovery, likewiſe obſerved, that the ſimple combuſtion of coals, as alſo the effervеſcence of iron filings and diluted ſulphuric acid produce the ſame effect; which is, in all probability, owing to the evaporation which attends thoſe proceſſes.

† See Joſ. Gardenii Diſſert. de Electrici ignis natura, p. 124.

‡ See my Treatiſe on Electricity, 4th edition, vol. III. p. 274.

This

This curious production of electricity by evaporation, as alſo the production of electricity by the condenſation of vapour, may be eaſily obſerved in the following manner:

Place a metallic cup, or a pewter plate, upon an inſulating ſtand, and connect a ſenſible electrometer with it. Alſo place one or two lighted coals in the cup or plate; then pour a little water at once upon the coal or coals, which will produce a quick evaporation, accompanied with a great hiſſing noiſe, and at the ſame time the electrometer will diverge with negative electricity.

tin

If the ſteam, which iſſues copiouſly from water quickly boiling, be received under a pretty large and inſulated metallic plate, that plate, by the condenſation of the ſteam upon it, will be electrified poſitively, as may be aſcertained merely by connecting a ſenſible electrometer with it.

On throwing a variety of other ſubſtances upon actually burning, or only hot and inſulated, coals, the coals, &c. either ſhewed negative electricity, or no electricity at all. Either ſpirit of wine, or ether when thus treated, left the coals negative; but if, (the coals being ſufficiently hot) the ſpirit of wine or the ether took fire, and burned in their uſual way, then no electricity was produced.

CHAP. IX.

ATMOSPHERICAL ELECTRICITY.

THE memorable year 1752 produced the remarkable diſcovery of the identity of lightning and electricity, which, previous to that year, had only been ſuſpected by philoſophers.

The ſimilarity of lightning to artificial electricity is not to be remarked in a few appearances only, but is obſervable throughout all their numerous effects; and there is not a ſingle phenomenon of the one, which may not be imitated by the other. Lightning deſtroys edifices, animals, trees, &c.—Lightning goes through the beſt conductors in its way; and if its paſſage be obſtructed by electrics, or leſs perfect conductors, it rends and diſperſes them in every direction; — lightning burns combuſtible bodies;—it melts metals;—a ſtroke of lightning often diſturbs the virtue of a magnet, and gives polarity to ferruginous ſubſtances; and all theſe effects may be produced upon a much ſmaller ſcale by means of artificial electricity. But independent of the great ſimilarity between the effects of of lightning and thoſe of electricity, what fully proves their identity, is, that the matter of lightning may be actually brought down from the clouds by means of inſulated metallic rods, or of electrical kites, and with it any known electrical experiment may be performed.

Clouds, as well as the rain, ſnow, and hail, which fall from them, alſo fogs, are almoſt always electrified, but oftener negatively than poſitively; and the lightning, accompanied with the thunder, is the effect of the electricity, which, darting from a cloud, or a number of clouds highly electrified, ſtrikes into another cloud, or elſe upon terreſtrial objects; in which caſe it prefers the loftieſt, moſt pointed, and beſt conducting objects; and by this ſtroke it produces all thoſe dreadful effects, which are known to be produced by lightning.

The air, at ſome diſtance from houſes, trees, maſts of ſhips, &c. is generally electrified almoſt always poſitively, eſpecially in froſty, clear, or foggy weather; but how the air, the fogs, and the clouds become electrified, has not yet been fully and clearly aſcertained. The moſt probable conjecture is grounded upon the effects of the evaporation of watery fluids, and the condenſation of vapour; but we ſhall in the firſt place deſcribe the inſtruments that are moſt uſeful for diſcovering this electricity; then ſhall ſtate the principal facts which have been obſerved with reſpect to this atmoſpherical electricity; and ſhall, laſtly, ſubjoin the moſt plauſible explanation,

tion, together with the advantage which is derived from the knowledge of the ſubject.

My electrometer in a phial, which has been already deſcribed (p. 392) is the beſt portable inſtrument for this purpoſe; for if you hold this electrometer by its lower part, and raiſe it juſt above the level of your head in the open air, when the air is ſtrongly electrified, or in a fog, or when electrified clouds are over head, and ſometimes even when they are a little way above the horizon; the divergency of the electrometer will announce the preence of electricity, and by the approach of an excited ſtick of ſealing-wax, or of any other electric, you may eaſily determine whether the electricity be poſitive or negative; obſerving that the electricity of the electrometer in this caſe is the contrary of that of the clouds or fog: but if the electrometer be electrified by the rain, or ſnow, or hail, falling upon it; then the electricity of the rain, &c. is the ſame as that of the electrometer; for in the latter caſe the electrometer is electrified by the contact, but in the former caſe it is electrified by the action of electric atmoſphere. See pages 353 and 359.

When the electricity of the air is not ſo ſtrong as to be diſcovered by this inſtrument, then an electrometer muſt be extended farther out into the air. For this purpoſe I have long uſed the following moſt commodious inſtrument or atmoſpherical electrometer.

A B, fig. 18, Plate XXIII. is a common jointed fiſhing-

fiſhing-rod, wanting the laſt or ſmalleſt joint. From the extremity of this rod proceeds a ſlender glaſs tube or glaſs ſtick C, which is covered with ſealing-wax, and has a cork D at its extremity, to which a cork-ball electrometer, E, is ſuſpended. HGI is a piece of common pack-thread, faſtened to the rod at A, and ſupported at G by a ſhort ſtring FG. At the extremity I of the pack-thread, a pin, or pointed wire, is faſtened, which when puſhed into the cork D, renders the electrometer E uninſulated.

When I wiſh to obſerve the electricity of the atmoſphere with this inſtrument, I thruſt the pin I into the cork D, and holding the rod by its lower end A, I project it out from an upper window, raiſing the end B with the electrometer, ſo as to make an angle of about 50° or 60°, with the horizon. In this ſituation I keep the inſtrument for a few ſeconds; then pulling the pack-thread at H, I diſengage the pin from the cork D; which operation cauſes the ſtring to drop in the dotted ſituation HK, and leaves the electrometer poſſeſſed of the electricity contrary to that of the atmoſphere.—This done, I draw the inſtrument within the room, and examine the quality of the electricity, without any obſtruction either from wind or darkneſs.

If any perſon wiſh to obſerve the electricity of the rain, he may either occaſionally uſe, or have always fixed, a rod or an aſſemblage of wires round a rod covered with ſealing-wax, cemented into a glaſs tube, by which it may be either held in the hand occaſionally, or may be permanently fixed within a room, and projecting about two or three feet out of a window; for which purpoſe either the window muſt be opened occaſionally, or the rod muſt paſs through a hole ſufficiently large. To that end of this rod which is within the room, an electrometer muſt be attached, and it will frequently happen, that when it rains, and the rain falls upon the projecting part of the rod, the electrometer at its internal extremity is electrified.

But an inſulated wooden rod, with a wire round it, and projecting about 15 or 16 feet above the houſe, will anſwer every purpoſe; for a wire proceeding from this rod may be made to communicate with an electrometer within the room, where the intenſity as well as the quality of the electricity may be obſerved. Such a rod however is very dangerous in time of a thunder ſtorm. In order to avoid the danger, a conducting communication, viz. a ball of braſs ſhould be placed at about two inches diſtance from the rod, and a thick wire ſhould be carried from this ball to the ground or to the pump, &c. in order that if a large quantity of electricity from a cloud ſtrike the rod, that electricity may be conveyed by the wire to the ground, without hurting the by-ſtanders*.

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* For the conſtruction of ſuch a rod, ſee Mr. J. Read's *Summary View of the ſpontaneous Electricity of the Earth and Atmoſphere.* London 1793.

When the electricity of the air, or rain, &c. is too weak to be diſcovered by thoſe inſtruments, then my multiplier may be uſed in conjunction with any of them; or the electricity of the atmoſphere may be diſcovered by means of an electrical kite; which is nothing more than a common paper kite, ſuch as is uſed by children, only having a ſtring which is rendered a better conductor by having a ſlender wire through it. The paper of the kite ſhould likewiſe be covered with drying linſeed oil, in order to defend it from the rain.

A kite of about four feet in height is the moſt commodious for this purpoſe. The ſtring is the moſt material part of this apparatus; for according as the ſtring is longer or ſhorter, a better or a worſe conductor, ſo is the electricity which is brought down by it ſtronger or weaker. The kite only ſerves to keep the ſtring up into the atmoſphere. After a variety of trials the beſt ſtring proved to be one which I made by twiſting a copper thread, (viz. ſuch as is uſed for trimmings, &c. in imitation of gold thread, which is nothing more than ſilk or linen thread covered over with a thin lamina of copper) with two very thin threads of twine.

When the kite is flying, the lower part of the ſtring muſt be inſulated by means of a ſilk ſtring of about two or three feet in length, or by means of a

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The famous Fr. Beccaria uſed a long chord extended in the atmoſphere between two houſes. See his Electricity.

glaſs ſtick, &c.; then at the lower extremity of the ſtring you may not only electrify an electrometer, but you may alſo draw ſparks, or charge a Leyden phial, &c. and that at every hour of the day or night, and at all times of the year, and will ſeldom fail. The reader is requeſted to obſerve and to remember, that this kite is dangerous during a ſtorm.

It appears, 1. That there is in the atmoſphere, at all times, a quantity of electricity; for whenever I uſe the above-deſcribed fiſhing-rod-electrometer in an open ſituation, it always acquires ſome electricity, and that electricity is always of the ſame kind, viz. negative; which ſhews that the electricity of the air or of fogs, is almoſt always poſitive, except when the inſtrument is influenced by clouds near the zenith.

2. That the ſtrongeſt electricity is obſervable in thick fogs, and likewiſe in froſty weather; but the weakeſt, when the weather is cloudy, warm, and very near raining; but it does not ſeem to be leſs at night than in the day time.

3. That in a more elevated place the electricity is generally ſtronger than in a lower one. Thus I have often obſerved the electrometer to diverge more in the iron than in the ſtone gallery on the outſide of the cupola of St. Paul's cathedral.

4. That the rain, ſnow, and hail, are more or leſs, but almoſt always electrified, much more frequently

frequently with negative than with poſitive electricity.

After a vaſt number of experiments with electrical kites during upwards of two years, I was enabled to form the following concluſions:

1. The air appears to be electrified at all times; its electricity is conſtantly poſitive, whether by day or night, and much ſtronger in froſty than in warm weather. My experiments have been made in every degree of temperature between 15° and 80°.

2. The preſence of clouds generally leſſens the electricity of the kite; ſometimes it has no effect upon it, and ſeldom increaſes it.

3. During rain the electricity of the kite is generally negative, and ſeldom poſitive.

4. The aurora borealis, or northern light, does not appear to affect the electricity of the kite.

5. The ſpark taken from the ſtring of the kite, or from any inſulated conductor which is connected with it, eſpecially when it does not rain, is very ſeldom longer than a quarter of an inch; but it is remarkably pungent; ſo that the operator will frequently feel the effect of it even in his legs; it appearing more like the diſcharge of an electric jar than like the ſpark which is taken from the prime conductor of an electrical machine.

6. The electricity which is brought down by the ſtring of the kite is, upon the whole, ſtronger or weaker, according as the ſtring is longer or ſhorter; but it does not keep any exact proportion to it; for

inſtance,

inſtance, the electricity from a ſtring of an 100 yards may raiſe the index of a quadrant electrometer 20°, whereas with double that length of ſtring the index will not riſe higher than about 25°.

7. When the weather is damp, and the electricity is pretty ſtrong, the index of the electrometer, after taking a ſpark from the ſtring, or preſenting the knob of a coated phial to it, riſes with ſurpriſing quickneſs to its uſual degree; but in dry and warm weather, it riſes remarkably ſlowly.

After the diſcovery of the identity of electricity and the matter of lightning, as alſo of the conſtant exiſtence of electricity in the atmoſphere, philoſophers endeavoured to attribute ſome other atmoſpherical and even terreſtrial phenomena to the agency of electricity. Thus the accenſions, commonly called *falling ſtars* or *ſhooting ſtars*; meteors, water-ſpouts, hurricanes, whirlwinds, &c. have been conſidered by ſeveral perſons as being electrical phenomena; but of this we have no poſitive proofs.

The *aurora borealis,* or northern light, ſeems moſt likely to be an electrical phenomenon; and this on two accounts, viz. firſt becauſe a magnetic needle appears a little diſturbed at the time of a ſtrong aurora borealis; and ſecondly, becauſe the aurora borealis may be partly imitated by means of artificial electricity *.

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* The *aurora borealis* is a phenomenon pretty well known to the preſent generation throughout Europe at leaſt. It

Take a glaſs phial nearly of the ſhape and ſize of a Florence flaſk; fix a ſtop-cock, or a valve to its neck, and exhauſt it as much as you can by means of a good air-pump. If then this glaſs be rubbed after the manner commonly uſed for exciting electrics, it will appear luminous within, being full of a flaſhing light, which plainly reſembles the *aurora borealis*. This phial may alſo be rendered luminous, if, holding it by either end, you bring its other end to the prime conductor; in this caſe all the cavity of the glaſs will inſtantly appear full of light, which may be ſeen flaſhing in it for a conſiderable time after it has been removed from the prime conductor, eſpecially if it be touched with the hand. This effect is eaſily deduced from the conducting nature of the vacuum, and from the charging and diſcharging of the glaſs.

The moſt plauſible mode of accounting for the electricity which is conſtantly to be obſerved in the atmoſphere, and which accompanies the clouds, the fogs, the rain, or that of thunder ſtorms, is to derive it from the evaporation of water, and from the condenſation

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It is a lambent or flaſhing light, which conſiſts of ſeparate coruſcations ſeen at night in ſome periods more often than in other. They dart quickly from one part of the ſky to another; they have different intenſities and different tints. Sometimes thoſe coruſcations, when ſtrong, are accompanied with a ſort of crackling noiſe diſtinctly audible, as I remember to have heard it more than once.

denſation of vapours. For though the electricity which is thus produced, may at firſt ſight appear too ſmall; yet if we conſider that thoſe proceſſes are continually carried on, both upon the ſurface of the earth and in the atmoſphere, we may eaſily acknowledge the ſufficiency of it.

When the vapours depart from the earth, they carry away a much greater quantity of the electric fluid, than they had when in the form of water, and which they have derived from the earth. Now if thoſe vapours, as they aſcend in the atmoſphere, become more rarefied, then, as they have no bodies at hand from which they can derive the electric fluid, which is required for their increaſed capacity, they muſt appear electrified negatively. On the contrary, if thoſe vapours are condenſed, then their capacity for the electric fluid being diminiſhed, they muſt appear electrified poſitively. Beſides, a cloud highly electrified may eaſily induce the contrary electricity in another contiguous cloud. From thoſe cauſes a variety of particular accumulations of poſitive or negative electricity, or of changes from the one to the other may be eaſily conceived, apparently ſufficient to account for the phenomena of atmoſpherical electricity.

One of the greateſt advantages which mankind has derived from the knowledge of this branch of philoſophy, is a defence for houſes, ſhips, &c. againſt the fatal effects of the lightning. It was propoſed by Dr. Franklin to erect an iron rod, or a wire of any

any metal on the top of a houſe, and to carry the communication by means of good conductors of electricity, from that rod down to the ground; for ſince the lightning generally ſtrikes the moſt elevated conductors, through which it paſſes to the earth, it was natural to ſuppoſe that the houſe thus furniſhed with a conductor, would be defended from the pernicious effects of lightning. This wiſe propoſal was generally adopted, and its uſefulneſs has been confirmed by innumerable caſes, eſpecially in warm climates, which are much more ſubject to thunder ſtorms.

The uſefulneſs of conductors to defend buildings from the effects of the lightning, has been univerſally acknowledged; but the proper form of thoſe conductors, eſpecially with reſpect to their terminations, has been the cauſe of much controverſy. It was objected to their having a pointed termination, that a pointed body can attract the electric fluid from a greater diſtance than a blunt termination, and therefore it would invite the lightning where otherwiſe the lightning would not go. To this it was replied, that though the point will attract the electric fluid from a greater diſtance, yet it will attract it in a ſtream, viz. by degrees, and not in a full body as a knob would do; by which means the force of the lightning will be diminiſhed, and in certain caſes a full ſtroke may thereby be entirely averted. In ſhort, after a great variety of arguments

arguments and experiments, the beſt conſtruction of ſuch conductors ſeems to be as follows *.

It ſhould conſiſt of a rod of iron, or of other metal, about three quarters of an inch thick, faſtened to the wall of the building, not by iron clamps, but by wooden ones. The rod ſhould be uninterrupted from the top of the building to the ground; or if it conſiſt of various pieces, care muſt be had to join the pieces as perfectly as poſſible. If this conductor ſtood quite detached from the building, and ſupported by pieces of wood at the diſtance of one or two feet from the wall, it would be better for common edifices; but it is particularly adviſeable for gun-powder magazines, gun-powder mills, and all ſuch buildings as contain combuſtibles ready to take fire. The upper end of the conductor ſhould terminate in one or more ſharp points; which, if the conductor be of iron, ought to be gilt, in order to prevent the ruſt or the oxigenation. This ſharp end ſhould be elevated above the higheſt part of the building (as above a ſtack of chimnies, to which it may be faſtened) at leaſt five or ſix feet. The lower end of the conductor ſhould be driven

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* See what relates to the conductors of lightning in the Philoſophical Tranſactions for the year 1777, and ten or twelve following years; alſo ſee Earl Stanhope's Principles of Electricity, London 1779, and my Treatiſe on Electricity, 4th edition, vol. II. p. 207, and following.

driven five or ſix feet into the ground, and in a direction leading from the foundation; or it would be better to connect it with the neareſt piece of water.

For an edifice of a moderate ſize, one of thoſe conductors is perhaps ſufficient; but a large building ought to have two, or three, or more conductors at its moſt diſtant parts.

On board of ſhips a chain has often been uſed on account of its pliableneſs; but in ſeveral caſes the chain has been actually broken by the lightning, in conſequence of the obſtruction which the electric fluid meets with in going through the various links; hence, inſtead of a chain, a copper wire about one-third part of an inch thick, is now more commonly uſed. One of thoſe wires ſhould be elevated two or three feet above the higheſt maſt in the veſſel; this ſhould be continued down along the maſt as far as the deck, where, by bending, it ſhould be adapted to the ſurface of ſuch parts as may be more convenient; and by continuing it down the ſide of the veſſel, it ſhould always be made to communicate with the water.

With regard to perſonal ſecurity in time of a thunder ſtorm, if a perſon be in a houſe which is not furniſhed with a conductor, it is adviſable not to ſtand near any metallic articles, viz. near gilt frames, chimney-grates, bell-wires, iron caſements, and the like. In the middle of a room, upon a dry chair, or table, or matraſſes, or other inſulating articles,

ticles, is the ſafeſt ſituation. Should a ſtorm happen when a perſon is in the open fields, and far from any building, the beſt thing he can do is to retire within a ſmall diſtance of the higheſt tree or trees he can get at; he muſt not, however, go quite near them, but he ſhould ſtop at about fifteen or twenty feet from their outermoſt branches; for if the lightning happen to ſtrike about the place, it will in all probability ſtrike the trees in preference to any other much lower object; and if a tree happen to be ſplit, the perſon will be ſafe enough at that diſtance from it.

CHAP. X.

OF ANIMAL ELECTRICITY.

UNDER this title we ſhall take notice of that electricity only which is produced from the animal itſelf, in conſequence of its particular organization, and not that which is produced by the application of metallic ſubſtances to animals.

Three fiſhes have hitherto been diſcovered to have, whilſt living, the ſingular property of giving ſhocks analogous to thoſe of artificial electricity; namely, the *torpedo*, the *gymnotus electricus*, and the *ſilurus electricus*. Thoſe animals belong to three different orders of fiſh; and the few particulars, which they ſeem to have in common, are the power of giving the ſhock; an organ in their bodies, called the *electric organ*, which is in all probability employed by thoſe animals for the exertion of that power; a ſmooth ſkin without ſcales; and ſome ſpots here and there on the ſurfaces of their bodies.

The torpedo, which belongs to the order of *rays*, is a flat fiſh, very ſeldom twenty inches long, weighing not above a few pounds when full grown, and is pretty common in various parts of the ſea-coaſt of Europe. The electric organs of this animal are two in number, and are placed one on each ſide of the cranium and gills, reaching from that place as far as the ſemicircular cartilages of each great fin, and extending longitudinally from the anterior extremity of the animal to the tranſverſe cartilage which divides the thorax from the abdomen. In thoſe places they fill up the whole thickneſs of the animal from the lower to the upper ſurface, and are covered by the common ſkin of the body, under which, however, are two thin membranes or *faſciæ*. The length of each organ is ſomewhat leſs than one-third part of the whole length of the animal. Each organ conſiſts of perpendicular columns, reaching from the under to the upper ſurface of the body, and varying in length according to the various thickneſs of the fiſh in various parts. The number of thoſe columns is not conſtant, differing in different torpedos, and likewiſe in different ages of the animals. In a very large torpedo, one electric organ was found to conſiſt of 1182 columns. The greateſt number of thoſe columns are either irregular hexagons, or irregular pentagons, but their figure is by no means conſtant. Their diameters are generally equal to one-fifth part of an inch*.

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* For farther particulars, ſee Hunter's Anatomical Obſervations on the Torpedo, Phil. Tranſ. vol. 63.

The above-mentioned electric organs ſeem to be the only parts employed to produce the ſhock *; the reſt of the animal appearing to be merely the conductor of that ſhock, as parts adjacent to the electric organs; and, in fact, the animal has been found to be a conductor of artificial electricity. The two great lateral fins, which bound the electric organs laterally, are the beſt conductors.

If the torpedo, whilſt ſtanding in water, or out of the water, but not inſulated, be touched with one hand, it generally communicates a trembling motion or ſlight ſhock to the hand; but this ſenſation is felt in the fingers of that hand only. If the torpedo be touched with both hands at the ſame time, one hand being applied to its under, and the other to its upper, ſurface, a ſhock in that caſe will be received, which is exactly like that which is occaſioned by the Leyden phial. When the hand touches the fiſh on its oppoſite ſurfaces, and juſt over the electric organs, then the ſhock is the ſtrongeſt; but if the hands be placed upon other parts of the oppoſite ſurfaces, the ſhocks are ſomewhat weaker; and no ſhock at all is felt when the hands are both placed upon the electric organs of the ſame ſurface; which ſhews that the upper and lower

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* The manner in which the electric fluid is accumulated or generated by thoſe organs, is by no means underſtood, but the ſubject of the next chapter may probably throw much light upon it.

ſurfaces of the electric organs are in oppoſite ſtates of electricity, anſwering to the *plus* and *minus* ſides of a Leyden phial. When the fiſh is touched by both hands on the ſame ſurface, and the hands are not placed exactly on the electric organs, a ſhock, though weak, is ſtill received; but in this caſe the oppoſite power of the other ſurface of the animal ſeems to be conducted over the ſkin.

The ſhock which is given by the torpedo, when ſtanding in air, is about four times as ſtrong as when ſtanding in water; and when the animal is touched on both ſurfaces by the ſame hand, the thumb being applied to one ſurface, and the middle finger to the oppoſite ſurface, the ſhock is felt much ſtronger than when the circuit is formed by the application of both hands. Sometimes the torpedo gives the ſhocks ſo quickly one after the other, that ſcarcely two ſeconds elapſe between them; and when, inſtead of a ſtrong determinate ſhock, it communicates only a *torpor*, that ſenſation is naturally attributed to the ſucceſſive and quick diſcharge of a great many conſecutive ſhocks.

This power of the torpedo is conducted by the ſame ſubſtances which conduct artificial electricity, and is intercepted by the ſame ſubſtances which are non-conductors of electricity: hence, if the animal, inſtead of being touched immediately by the hands, be touched by non-electrics, as wires, wet cords, &c. held in the hands of the experimenter, the ſhock will be communicated through them. The circuit

circuit may alſo be formed by ſeveral perſons joining hands, and the ſhock will be felt by them all at the ſame time. If, when the animal is in water, the hands be put in the ſame water, a ſhock will alſo be felt, which will be ſtronger if one of the hands touch the fiſh, whilſt the other is kept in the water at a diſtance from it. In ſhort, the ſhock of this animal is conducted by the ſame conductors as that of the Leyden phial; thus it may paſs through more than one circuit at the ſame time; or the circuit may be much extended, &c. but in thoſe caſes the ſhock is much weakened.

The ſhock of the torpedo cannot paſs through the leaſt interruption of continuity: thus it will not be conducted by a chain, nor will it paſs through the air from one conductor to the other, when the diſtance is even leſs than the 200th part of an inch; conſequently no ſpark was ever obſerved to accompany it.

No electric attraction or repulſion was ever obſerved to be produced by the torpedo; nor indeed by any of the electric fiſhes, though ſeveral experiments have been inſtituted expreſsly for that purpoſe.

Theſe ſhocks of the torpedo ſeem to depend on the will of the animal; for each effort is accompanied with a depreſſion of its eyes, by which even his attempts to give it to non-conductors, may be obſerved. It is not known whether both electric organs muſt always act together, or one of them only, may be occaſionally put in action by the will of the animal.

Almoſt all thoſe effects of the torpedo may be imitated by means of a large electrical battery weakly charged *.

The gymnotus electricus has been frequently called *electrical eel*, on account of its bearing ſome reſemblance to the common eel. The gymnotus is found pretty frequently in the great rivers of South America. Its uſual length is about three feet; but ſome of them have been ſaid to be ſo large as to be able to ſtrike a man dead with their electric ſhock. A few of thoſe animals, about three feet long, were brought alive to England about thirty years ago, and a great many experiments were made with them.

A gymnotus of three feet in length generally is between 10 and 14 inches in circumference at the thickeſt part of its body. The electric power of this animal being much greater than that of the torpedo, its electric organs are accordingly a great deal larger, and indeed that part of its body which contains moſt of the animal parts that are common to the ſame order of fiſhes, is conſiderably ſmaller than that which is ſubſervient to the electric power, though the latter muſt naturally derive nouriſhment and action from the former. The head of the

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* See Mr. Walſh's Paper in the 63d volume of the Philoſophical Tranſactions.

animal is large, broad, flat, ſmooth, and impreſſed with various ſmall holes. The mouth is rather large, but the jaws have no teeth, ſo that the animal lives by ſuction, or by ſwallowing the food entire. The eyes are ſmall, flattiſh, and of a bluiſh colour, placed a little way behind the noſtrils. The body is large, thick, and roundiſh, for a conſiderable diſtance from the head, and then diminiſhes gradually. The whole body, from a few inches below the head, is diſtinguiſhed into four longitudinal parts, clearly divided from each other by lines. The *carina* begins a few inches below the head, and widening as it proceeds, reaches as far as the tail, where it is thinneſt. It has two pectoral fins, and the *anus* is ſituated on the under part, more forward than thoſe fins, and of courſe not far diſtant from the *roſtrum*.

This animal has two pairs of electric organs, one pair being larger than the other, and occupying moſt of the longitudinal parts of the body. They are divided from each other by peculiar membranes*.

The nerves which go to the electric organs of the gymnotus, as well as of the torpedo, are much larger than thoſe which ſupply any other part of

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* See Hunter's Account of the Gymnotus Electricus, in the 65th Volume of the Philoſophical Tranſactions, for farther Particulars. Alſo my Treatiſe on Electricity, 4th Edition, Vol. II. Appendix, N° VII.

the body. The electric organs of the gymnotus are ſupplied with nerves from the ſpinal marrow, and they come out in pairs between the vertebræ of the ſpine.

The gymnotus poſſeſſes all the electric properties of the torpedo, but in a ſuperior degree. His ſhock is conducted by conductors of electricity; it is communicated through water, &c. The ſtrongeſt ſhock is received when, the animal ſtanding out of the water, you apply one hand towards the tail, and the other towards the head of the animal. In this manner I often received ſhocks from one of thoſe animals, which I felt not only in my arms, but very forcibly even in my cheſt. If the animal be touched with one hand only, then a kind of tremor is felt in that ſingle hand, which, though ſtronger, is, however, perfectly analogous to that which is given by the torpedo when touched in the like manner.

This power of the gymnotus is likewiſe depending on the will of the animal, ſo that ſometimes he gives ſtrong ſhocks, and at other times very weak ones. He gives the ſtrongeſt ſhocks when provoked by being frequently and roughly touched.

When ſmall fiſhes are put into the water, where the gymnotus is, they are frequently ſtunned, and are either effectually or apparently killed.

The ſtrongeſt ſhocks of the gymnoti, which were exhibited in London, would paſs through a very ſhort interruption of continuity in the circuit. They could be conveyed by a ſhort chain when ſtretched, ſo as to bring the links into a more perfect contact. When the interruption was formed by the inciſion made with a pen-knife on a ſlip of tin-foil that was paſted upon glaſs, the ſhock in paſſing through that interruption, ſhewed a ſmall but vivid ſpark, plainly viſible in a dark room.

This animal ſhewed a peculiar property, namely that of knowing when he could, and when he could not, give the ſhock; for if non-conductors or interrupted circuits were placed in the water, he would not approach them; but as ſoon as the circuit was completed, he would approach the extremities of that circuit, and immediately give the ſhock*.

The third fiſh which is known to have the power of giving the ſhock, is found in the rivers of Africa; but we have a very imperfect account of its properties †.

This animal belongs to the order which the naturaliſts call *ſilurus*; hence its name is *ſilurus electricus*. The length of ſome of thoſe fiſhes have been found to exceed 20 inches.

The body of the ſilurus electricus is oblong, ſmooth, and without ſcales; being rather large, and

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* See my Treatiſe on Electricity, 4th edition, vol. II. p. 309.

† Meſſrs. Adanſon and Forſkal make a ſhort mention of it; and Mr. Bruſſonet deſcribes it under the French name of *le Trembleur*, in the *Hiſt. de l'Acad. Royale des Sciences*, for the year 1782.

flattened

flattened towards its anterior part. The eyes are of a middle ſize, and are covered by the ſkin, which envelopes the whole head. Each jaw is armed with a great number of ſmall teeth. About the mouth it has ſix filamentous appendices, viz. four from the under lip, and two from the upper; the two external ones, or farthermoſt from the mouth on the upper lip, are the longeſt. The colour of the body is greyiſh, and towards the tail it has ſome blackiſh ſpots.

The electric organ ſeems to be towards the tail, where the ſkin is thicker than on the reſt of the body, and a whitiſh fibrous ſubſtance, which is probably the electric organ, has been diſtinguiſhed under it.

It is ſaid that the ſilurus electricus has the property of giving a ſhock or benumbing ſenſation, like the torpedo, and that this ſhock is communicated through ſubſtances that are conductors of electricity. No other particular ſeems to be known concerning it.

Nature ſeems to have given thoſe fiſhes this ſingular power of giving the ſhock for the purpoſe of ſecuring their prey, by which they muſt ſubſiſt; and perhaps likewiſe for the purpoſe of repelling larger animals, which might otherwiſe annoy them.

The ancients conſidered the ſhocks of the torpedo as capable of curing various diſorders; and a modern philoſopher will hardly heſitate to credit their

aſſertions,

aſſertions, ſince electricity has been found to be a uſeful remedy in ſeveral caſes.

A fourth fiſh, ſaid to give ſhocks like the abovementioned, was found on the coaſt of Johanna, one of the Comoro iſlands, in lat. 12° 13′ ſouth, by Lieutenant William Paterſon, and an imperfect account of it is given in the 76th volume of the Philoſophical Tranſactions.

" The fiſh is deſcribed to be 7 inches long, 2 $\frac{5}{8}$
" inches broad, has a long projecting mouth, and
" ſeems of the genus Tetrodon. The back of the
" fiſh is a dark brown colour, the belly part of ſea-
" green, the ſides yellow, and the fins and tail of a
" ſandy green. The body is interſperſed with red,
" green, and white ſpots, the white ones particularly
" bright; the eyes large, the iris red, its outer edge
" tinged with yellow."

Whilſt this fiſh is living, ſtrong ſhocks, like electrical ſhocks, are felt by a perſon who attempts to hold it between his hands. Three perſons only are mentioned in the account as having experienced this property of one of thoſe fiſhes; but the want of opportunity prevented the trial of farther experiments.

CHAP. XI.

OF GALVANISM.

IN the year 1791, a very remarkable diſcovery made by Dr. Galvani of Bologna was announced to the ſcientific world in a publication entitled, *Aloyſii Galvani de Viribus Electricitatis in motu muſculari Commentarius. Bononiæ* 1791.

The diſcoveries of Dr. Galvani were made principally with dead frogs. He in the firſt place diſcovered that a frog dead and ſkinned, is capable of having its muſcles brought into action by means of electricity, even in exceedingly ſmall quantities.

Secondly, that independant of any apparent electricity, the ſame motions may be produced in the dead animal, or even in a detached limb, merely by making a communication between the nerves and the muſcles, with ſubſtances that are conductors of electricity. If the circuit of communication conſiſt of non-conductors of electricity, as glaſs, ſealing-wax, and the like, no motion will take place.—The like experiments were alſo ſucceſsfully inſtituted upon other animals; and as the power ſeemed to be inherent in the animal parts, thoſe experiments, or the power which produces the motion of the muſcles in thoſe experiments, was denominated *animal electricity.* But it being now fully aſcertained, that by the mere contact of metallic and other conducting ſubſtances, ſome electricity is generated *, it is evident that the muſcular motions in the abovementioned experiments are produced by that electricity; hence we have confined the *name of animal electricity* to denote the power of the fiſhes which give the ſhock, &c. as deſcribed in the preceding chapter. And, at leaſt for the preſent, we ſhall examine the electricity which is produced by the contact, or by the action, of metallic and other conducting ſubſtances upon each other, under the title of *Galvaniſm*; though in truth Galvani's diſcoveries go no farther than what relates to certain effects of the contact of animal parts principally with metallic ſubſtances.—I ſhall briefly deſcribe the principal facts which relate to the above-mentioned ſort of muſcular motion, and ſhall then proceed to thoſe which relate to the wonderful effects of the mere contact or action of one conducting ſubſtance upon another, amongſt which the metallic are the moſt conſpicuous.

The action of electricity on a frog, recently dead,

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* See Bennet's *New Experiments on Electricity*, 1789; and my Treatiſe on Electricity, 4th Edition, vol. III. p. 111, and following.

and ſkinned, (and indeed on other animals more or leſs) occaſions a tremulous motion of the muſcles, and generally an extenſion of the limbs.

Dr. Galvani uſed to ſkin the legs of a frog recently dead, and to leave them attached to a ſmall part of the ſpine, but ſeparated from the reſt of the body.—Any other limb may be prepared in a ſimilar manner; viz. the limb is deprived of its integuments, and the nerve, which belongs to it, is partly laid bare.

If the limbs thus prepared, for inſtance, the legs of a frog, be ſituated ſo that a little electricity may paſs through them, be it by the immediate contact of an electrified body, or by the action of electric atmoſpheres (as when the preparation is placed within a certain diſtance of an electrical machine, and a ſpark is taken from the prime conductor); the prepared legs will be inſtantly affected with a kind of ſpaſmodic contraction, ſometimes ſo ſtrong as to jump a conſiderable way.

When the electricity is cauſed to paſs through the prepared frog by the immediate contact of the electrified body, a much ſmaller quantity of it is ſufficient to occaſion the movements, than when it is made to paſs from one conductor to another, at a certain diſtance from the prepared animal*.

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* Probably the 100th part of that electricity which can affect a very delicate electrometer, is ſufficient to produce the movement of the prepared animal limb, and even of a whole frog, or mouſe, or ſparrow, &c.

The movements are much ſtronger when the electricity is cauſed to paſs through a nerve to the muſcle or muſcles, than through any other part.

The ſenſibility of the prepared animal is greateſt at firſt, but it diminiſhes by degrees till it vaniſhes entirely. Animals with cold blood, and eſpecially frogs, retain that ſenſibility for ſeveral hours, ſometimes even for a day or two. With other animals the ſenſibility does not laſt long after death, and ſometimes not above a few minutes.

The like movements may be produced in the prepared animal without the aid of any apparent electricity. In an animal recently dead, detach one end of a nerve from the ſurrounding parts, taking care to cut it not too near its inſertion into the muſcle; remove the integuments from over the muſcles which depend on that nerve; take a piece of metal, as a wire, touch the nerve with one extremity of it, and the muſcles with its other extremity; on doing which you will find that the prepared limbs move in the ſame manner as when ſome electricity is paſſed through them. This however is not the moſt effectual way of forming the communication; yet it will generally ſucceed, and the experiment will anſwer whether the preparation be laid upon conductors or upon electrics.

If the communication between the nerve and the muſcle be formed by the interpoſition of non-conductors of electricity, ſuch as glaſs, ſealing-wax, &c. then no movements will take place.

When the application of the metal or metals is continued upon the parts, the contractions will ceaſe after a certain time, and on removing the metal, ſeldom, if ever, any contraction is obſerved.

The conducting communication between the muſcle and the nerve may conſiſt of one or more pieces, and of the ſame or, much better, of different bodies connected together, as metals, water, a number of perſons, and even wood, the floor of a room, &c.* But it muſt be obſerved, that the leſs perfect conductors will anſwer only at firſt, when the prepared animal is vigorous; but when the power begins to diminiſh, then the more perfect conductors only will anſwer, and even theſe will produce various effects.

The moſt effectual way of producing thoſe movements in prepared animal parts is by the application of two metals, of which ſilver and zinc ſeem upon the whole to be the beſt, though ſilver and tin, or copper and zinc, and other combinations, are not much inferior. If part of the nerve proceeding from a prepared limb be wrapped up in a bit of tin-foil, or be only laid upon zinc, and a piece of ſilver be laid with one end upon the bare muſcle, and with the other upon the above-mentioned tin or zinc, the motion of the prepared limb will be very vigorous. The two metals may be placed not in contact with the preparation, but in any other

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* The various bodies, which form this circuit, muſt be placed in full and perfect contact with each other, which is done by preſſing them againſt each other, or by the interpoſition of water, &c.

part of the circuit, which may be compleated by means of other conductors, as water, &c.

The beſt preparation for this experiment is made in the following manner:

Separate with a pair of ſciſſars the head and upper extremities of a frog from the reſt of the body. Open the integuments and muſcles of the abdomen, and remove the entrails, by which means you will lay bare the crural nerves. Then paſs one blade of the ſciſſars under the nerve, and cut off the ſpine with the fleſh cloſe to the thighs, by which means the legs will remain attached to the ſpine by the nerves alone. This done, leave a ſmall bit only of the ſpine attached to the crural nerves, and cut off all the reſt. Thus you will have the lower limbs G, H, fig. 1, Plate XXIV. of the frog adhering to the bit of ſpine, A B, by means of the crural nerves C, D. Theſe legs muſt be flayed in order to lay bare the muſcles; and a bit of tin-foil ſhould be wrapped round the ſpine A B. With this preparation the experiment may be performed various ways, but the two which follow are the beſt.

Hold the preparation by the extremity of one leg, the other leg hanging down, with the armed bundle of nerves and ſpine laying upon it. In this ſituation interpoſe a piece of ſilver, as a half-crown, between the lower thigh and the nerves, ſo that it may touch the former with one ſurface, and the metallic coating of the latter with the other ſurface, or with its edge; and you will find that the hanging leg will vibrate very powerfully, ſometimes ſo far as to ſtrike againſt the hand of the operator, which holds the other leg.

Otherwiſe, place two wine glaſſes, both full of water, contiguous to each other, but not actually touching. Put the thighs and legs of the preparation in the water of one glaſs, and laying the nerves over the edges of the two glaſſes, let the bit of ſpine with its armour (viz. tin-foil) touch the water of the other glaſs. Things being thus prepared, if you form the communication between the waters of the two glaſſes, by means of ſilver, or put the fingers of one hand into the water of the glaſs that contains the legs, and holding a piece of ſilver in the other, you touch the coating of the nerves with it, you will find that the prepared legs move ſo powerfully as ſometimes to jump fairly out of the glaſs.

By the application of armours of different metallic ſubſtances, and forming a communication between them, the motions may be excited even in an entire living frog, as alſo in ſome other living animals, particularly eels and flounders. The living frog is placed upon a piece of zinc, with a ſlip of tin foil paſted upon its back. This done, whenever the communication is formed between that zinc and the tin-foil, eſpecially if ſilver be uſed, the ſpaſmodic convulſions are excited, not only in the muſcles which touch the metallic ſubſtances, but likewiſe in the neighbouring muſcles. This experiment may be performed entirely under water.

The experiment may be performed with a flounder in a ſimilar, eaſy, and harmleſs manner. Take a living a living flounder, ſuch as may almoſt always be found at the fiſhmonger's; wipe it pretty dry, and lay it flat into a pewter plate, or upon a ſheet of tin-foil, and place a piece of ſilver, as a ſhilling, a crown piece, &c. upon the fiſh. Then, by means of a piece of metal, complete the communication between the pewter plate or tin-foil and the ſilver piece; on doing which the animal will give evident tokens of being affected. The fiſh may afterwards be replaced in water, and preſerved for farther uſe.

It ſeems that ſuch movements may be excited by the contact of metallic ſubſtances in all the animals; at leaſt they have ſucceeded, but in different degrees, in a great variety of animals, from the ox to the fly.

The human body, whilſt undergoing certain chirurgical operations, or its amputated limbs, have been convulſed by the application of metals. But the living animal body may be rendered ſenſible of the action of metallic application in an harmleſs way, and both the ſenſes of taſte and of ſight may be affected by it, but in different degrees according to the various conſtitutions of individuals.

Let a man lay a piece of metal upon his tongue, and a piece of ſome other metal under the tongue; on forming the communication between thoſe two metals, either by bringing their outer edges in contact, or by the interpoſition of ſome other piece of metal, he will perceive a peculiar ſenſation, a kind of irritation, accompanied with a ſort of cool and ſubacid taſte, not exactly like, and yet not much different from that which is produced by artificial electricity.

electricity. The metals which anſwer beſt for theſe experiments, are ſilver and zinc, or gold and zinc. The ſenſation ſeems to be more diſtinct when the metals are of the uſual temperature of the tongue. The ſilver or gold may be applied to any other part of the mouth, to the noſtrils, to the ear, or to other ſenſible parts of the body, whilſt the zinc is applied to the tongue; and on making the communication between the two metals, the taſte will be perceived upon the tongue. The effect is rather more remarkable when the zinc touches the tongue in a ſmall part, and the ſilver in a great portion of its ſurface, than *vice verſa.* Inſtead of the tongue, the two metals may alſo be placed in contact with the roof of the mouth, as far back as poſſible; and on compleating the communication, the taſte or irritation will be perceived.

Different perſons are variouſly affected by this application of metals; with ſome the ſenſation or taſte is ſo ſlight as to be hardly perceived, whilſt with others it is very ſtrong and even diſagreeable. Some perſons feel merely a pungency, and not properly a taſte.

In order to affect the ſenſe of ſight by means of metals, let a man in a dark place put a ſlip of tin-foil upon the bulb of one of his eyes, and let him put a piece of ſilver, as a ſpoon or the like, in his mouth. On completing the communication between the ſpoon and the tin-foil, a faint flaſh of white light will appear before his eyes. This experiment may be performed

performed in a more convenient manner, by placing a piece of zinc between the upper lip and the gums, as high up as poſſible, and a ſilver piece of money upon the tongue; or elſe by putting a piece of ſilver high up in one of the noſtrils, and a piece of zinc in contact with the upper part of the tongue; for in either caſe the flaſh of light will appear whenever the two metals are made to communicate, either by the immediate contact of their edges, or by the interpoſition of other good conductors.

By continuing the contact of the two metals, the appearance of light is not continued, it being only viſible at the moment of making the contact, and ſometimes, though rarely, at the inſtant of ſeparation: it may therefore be repeated at pleaſure, by disjoining, and again connecting, the two metals. When the eyes are in a ſtate of inflammation, then the appearance of light is much ſtronger.

When the ſcience of electricity was advanced no farther than the knowledge of the above-mentioned facts, it was doubtful whether the convulſions of prepared animal limbs, and the ſenſations which are produced by the application of metallic ſubſtances, were owing to ſome electrical property peculiar to the animal parts, which might perhaps be conducted through the metals from one part to the other; or to a ſmall quantity of electricity, which might be ſupplied by the metals themſelves. The latter ſuppoſition however was ſoon verified by the reſult of various experiments, which

which prove in the moſt convincing manner that electricity is produced by the mere contact, not only of metallic ſubſtances, but likewiſe of other bodies.

The electricity thus produced by the mere contact of two bodies is ſo very ſmall as not to be perceived without great care, and without uſing ſome of thoſe artifices for diſcovering ſmall quantities of electricity, which have been mentioned above. But the late diſcoveries of the ingenious Mr. Volta have ſhewn a method of increaſing that electricity to a moſt extraordinary degree *; by which means the ſubject of electricity has received a remarkable advancement, and has opened a moſt promiſing field of wonders, wherein numerous and able labourers are daily making uſeful and admirable diſcoveries.— We ſhall now proceed to ſtate thoſe facts in as compendious a manner as the nature of the ſubject will admit of, conſiſtently with perſpicuity.

The action of metallic ſubſtances upon the organs of living, or of recently dead animals, has been fully manifeſted by the above-mentioned diſcoveries of Galvani and others; but, previous to thoſe diſcoveries, a variety of facts, frequently aſſerted, imperfectly known, and often diſbelieved, indicated a peculiar action ariſing from a combination of different metallic bodies in certain caſes.

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* See his Paper in the Philoſophical Tranſactions for the year 1800, Art. XVII.

It had been long aſſerted, that when porter (and ſome other liquors alſo) is drank out of a pewter pot, it has a taſte different from what it has when drank out of glaſs or earthen ware.

tin

It has been obſerved, that pure mercury retains its metallic ſplendor during a long time; but its amalgam with any other metal is ſoon tarniſhed or oxidated.

The Etruſcan inſcriptions, engraved upon pure lead, are preſerved to this day; whereas ſome medals of lead and tin, of no great antiquity, are much corroded.—Works of metal, whoſe parts are ſoldered together by the interpoſition of other metals, ſoon tarniſh about the places where the different metals are joined.

When the copper ſheeting of ſhips is faſtened on by means of iron nails, thoſe nails, but particularly the copper, are readily corroded about the place of contact *.

It had been obſerved, that a piece of zinc might be kept in water for a conſiderable time, without hardly oxidating at all; but that the oxidation would ſoon take place if a piece of ſilver happened to touch the zinc, whilſt ſtanding in water.

Since Galvani's diſcoveries, the action ariſing from the combination of three conductors has been

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* See Fabroni's Paper on the Action of different Metals upon each other, in the 40th Number of Nicholſon's Journal.

examined

examined with great care, and with conſiderable ſucceſs, eſpecially by Mr. Volta, who lately diſcovered that the ſlight effect of ſuch a combination may be increaſed to a prodigious degree by repeating the combination; for inſtance, if a combination of ſilver, zinc, and water, produce a certain effect, a ſecond combination (viz. another piece of ſilver, another piece of zinc, and another quantity of water) added to the firſt, will increaſe the effect; the addition of a third combination will increaſe the effect ſtill more, and ſo on*.

Previous to the deſcription of the conſtruction, and of the very remarkable effects of thoſe repeated combinations, which are now generally called *Galvanic batteries* (though in juſtice they muſt be called *Volta's batteries*, or *Voltaic batteries)* it will be neceſſary to ſtate the principal laws, which have been pretty well aſcertained with reſpect to the ſimple combinations.

I. The conductors of electricity, which, ſtrictly ſpeaking, do almoſt all differ from each other in conducting power, are nevertheleſs divided into two principal claſſes. Thoſe of the firſt claſs, otherwiſe called *dry* and *perfect* conductors, are the metallic ſubſtances and charcoal. Thoſe of the ſecond claſs, or the *imperfect conductors*, are water and other oxidating fluids, as alſo the ſubſtances which contain

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* See his very valuable Paper in the Phil. Tranſ. for the year 1800, Art. XVII.

thoſe fluids. But as the ſubſtances of the ſecond claſs differ in conducting power much more than thoſe of the firſt claſs, ſo they may be ſubdivided into ſpecies*.

II. The ſimpleſt combinations capable of producing Galvanic effects, (viz. to convulſe the prepared limbs of a frog, or of exciting the taſte upon the tongue, &c.) muſt conſiſt of three different conductors; for, two conductors only will not produce any ſenſible effect. If the three conductors be all of the firſt claſs, or all of the ſecond, then the effect is ſeldom ſenſible. In this caſe ſuch conductors of the ſecond claſs as differ more from each other, are more likely to produce a ſenſible effect than thoſe of

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* Mr. Volta arranges thoſe ſubſtances in the following order, commencing with the leaſt active; obſerving, however, that this order is ſubject to a conſiderable deviation, eſpecially with reſpect to the latter ſpecies, and according as they are combined with certain bodies of the firſt claſs.

" 1. Pure water;" (It may be obſerved, that water holding in ſolution common air, and eſpecially oxigen air, is much more active than water deprived of air by boiling or otherwiſe.) " 2. Water mixed with clay or chalk; 3. A ſo-" lution of ſugar; 4. Alcohol; 5. Milk; 6. Mucilaginous " fluids; 7. Animal gelatinous fluids; 8. Wine; 9. Vine-" gar and other vegetable juices and acids; 10. Saliva; " 11. Mucus from the noſe; 12. Blood; 13. Brains; " 14. Solution of ſalt; 15. Soap ſuds; 16. Chalk water; " 17. Concentrated mineral acids; 18. Strong alkaline " leys; 19. Alkaline fluids; 20. Livers of ſulphur."

the firſt claſs [*]. But a proper active ſimple combination muſt conſiſt of three different bodies; viz. of one conductor, of one claſs, and two different conductors of the other claſs. Thus (denoting the bodies of the firſt claſs by means of large capital letters, and thoſe of the ſecond claſs by ſmall letters) the combinations of fig. 2, and 3, Plate XXIV. are active; but thoſe of fig. 4, 5, 6, 7, and 8, are not active, becauſe that of fig. 4, 5, or 6, conſiſts of two bodies only, and that of fig. 7, or 8, conſiſts of three bodies, of which two are of the ſame ſort, and of courſe act as a ſingle body.

When two of the three bodies are of the firſt claſs, and one is of the ſecond, the combination is ſaid to be of the *firſt order*; otherwiſe it is ſaid to be of the *ſecond order*.

In a ſingle active Galvanic combination, or, as it is commonly called, in a *ſimple Galvanic circle*, the two bodies of one claſs muſt touch each other in one or

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[*] Mr. Volta adduces as an inſtance of an active Galvanic combination, conſiſting of three conductors of the ſecond claſs only, an experiment of Dr. Valli, in which the three bodies concerned were, 1ſt, The leg of a frog, and particularly the hard tendinous part of the *muſculus gaſtroenemius*; 2d. The rump, or the muſcles of the back, or the iſchiatic nerves, to which the ſaid tendinous parts are applied; and 3d. The blood or the viſcous ſaponaceous or ſaline fluid, applied to the point of contact. See his letter to Gren in the *Neuves Journal des Phyſ.* vol. III. p. 4, and vol. IV. page 1.

more points, at the ſame time that they are connected together at other points by the body of the other claſs. Thus, when a prepared frog is convulſed by the contact of the ſame piece of metal in two different places; then the fluids of thoſe parts, which muſt be ſomewhat different from each other, are the two conductors of the ſecond claſs, and the metal is the third body, or the conductor of the firſt claſs. If two metals be uſed, then the fluids of the prepared animal, differing but little from each other, may be conſidered as one body of the ſecond claſs. Thus alſo, when a perſon drinks out of a pewter mug, the ſaliva or moiſture of his under lip is one fluid or one conductor of the ſecond claſs, the liquor in the mug is the other, and the metal is the third body, or conductor, of the firſt claſs.

III. It ſeems to be indiſpenſably requiſite, that in a ſimple Galvanic circle, the conductor or conductors of one claſs ſhould have ſome chemical action upon the other conductor or conductors; without which circumſtance the combination of three bodies will have either no Galvanic action at all, or a very ſlight one. Farther, the Galvanic action ſeems to be proportionate to the degree of chemical agency; which ſeems to ſhew that ſuch chemical action is the primary cauſe of the electric phenomena*.

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* Phil. Tranſ. for the year 1801, page 427.

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The moſt active Galvanic circles of the firſt order, are when two ſolids of different degrees of oxidability are combined with a fluid capable of oxidating at leaſt one of the ſolids. Thus gold, ſilver, and water, do not form an active Galvanic circle; but the circle will become active if a little nitric acid, or any fluid decompoſible by ſilver, be mixed with the water.

A combination of zinc, ſilver, and water, forms an active Galvanic circle, and the water is found to oxidate the zinc, provided the water holds ſome atmoſpherical air, as it commonly does, and eſpecially if it contain oxygen air. But zinc, ſilver, and water containing a little nitric acid, form a more powerful Galvanic circle, the fluid being capable of acting both upon the zinc and upon the ſilver.

The moſt powerful Galvanic combinations of the ſecond order, are when two conductors of the ſecond claſs have different chemical actions on the conductors of the firſt claſs, at the ſame time that they have an action upon each other. Thus copper, or ſilver, or lead, with a ſolution of an alkaline ſulphuret, and diluted nitrous acid, form a very active Galvanic circle.

The preſent ſtate of knowledge, relative to this ſubject, does not enable us accurately to determine the peculiar powers of all ſorts of Galvanic combinations; however, the following liſts contain a uſeful arrangement of the beſt combinations, diſpoſed in the order

order of their powers, and commencing with the moſt powerful [*].

Galvanic Circles of the Firſt Order, viz. *which conſiſt of two Conductors of the Firſt Claſs, and one of the Second.*

Zinc with gold, or charcoal, or ſilver, or copper, or tin, or iron, or mercury; and water containing a ſmall quantity of any of the mineral acids [†].

Iron, with gold, or charcoal, or ſilver, or copper, or tin, and a weak ſolution of any of the mineral acids, as above.

Tin, with gold, or ſilver, or charcoal, and a weak ſolution of any of the mineral acids, as above.

Lead, with gold, or ſilver, and a weak acid ſolution, as above.

Any of the above metallic combinations, and common water, viz. water containing atmoſpherical air, or eſpecially water containing oxygen air.

Copper, with gold, or ſilver, and a ſolution of nitrate of ſilver and mercury; or the nitric acid; or the acetous acid.

Silver, with gold, and the nitric acid.

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[*] This arrangement has been formed principally by Mr. Davy, profeſſor of chemiſtry at the Royal Inſtitution.

[†] Van Marum found a ſolution of ſalt ammoniac, viz. of the muriate of ammoniac, to act beſt.

Galvanic Circles of the Second Order, viz. *which conſiſt of one Conductor of the Firſt Claſs, and two of the Second.*

Charcoal, or Copper, or Silver, or Lead, or Tin, or Iron, or Zinc,	with water, or with a ſolution of any hydrogenated alkaline ſulphurets, capable of acting on the firſt three metals only;	and a ſolution of nitrous acid, or oxygenated muriatic acid, &c. capable of acting upon all the metals.

The action of a ſimple Galvanic circle ſeems to be in ſome meaſure dependent upon the quantity of ſurface of contact between the acting bodies. An higher temperature within certain limits, renders the activity of the circle greater than a lower temperature.

The activity of a Galvanic circle is not altered by the interpoſition of ſuch conductors as have no action upon the adjoining conductors of the circle. Thus, if a circle conſiſt of zinc, gold, and water; and if you interpoſe a piece of iron, or of ſilver, or both, between the zinc and the gold, the activity of the circle will not be altered thereby. Hence it appears that the action of a Galvanic circle may be conveyed through extraneous conductors to a conſiderable diſtance; but it muſt be obſerved, that the activity is weakened by the great length of the conductors, eſpecially if they be of an imperfect nature.

IV. When the three bodies which form a Galvanic circle of the firſt order are laid one upon the other, but the lower and the upper one do not touch each other; then theſe two extremes are in oppoſite electric ſtates, viz. the extremity which is next to that metallic ſurface that touches the body of the ſecond claſs, is poſitive, and the oppoſite extremity is negative. Thus let copper, zinc, and moiſtened leather, be laid one upon the other, as in fig. 9, Plate XXIV. and the upper end W, viz. the wetted leather, will be found poſſeſſed of poſitive electricity; whilſt the lower end C, or the copper, will be found negative *.

V. The

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* This is a very delicate experiment, and the electricity can only be rendered ſenſible by means of Volta's condenſer, or of my multiplier. I placed a plate of zinc, 3 inches in diameter, upon a larger plate of copper, and a piece of leather not quite 3 inches in diameter, ſoaked in common river water, was laid upon the zinc. Then whilſt the copper plate C, fig. 9, was made to communicate with the ground, a wire connected the leather W, with the receiving plate A of the multiplier, fig. 19, Plate XXIII. and by working that inſtrument after the manner which is deſcribed in page 426, it appeared that the moiſt leather gave poſitive electricity. When the three bodies were reverſed, viz. the moiſtened leather was placed upon the table, and the copper was made to communicate with the receiving plate of the multiplier, the latter acquired the negative electricity. This was tried repeatedly, and anſwered conſtantly. From theſe

V. The Galvanic effects may be increaſed to almoſt any degree, by connecting ſeveral of the above-mentioned active combinations, or by a repetition of the ſame ſimple Galvanic combination (the moſt active ſimple combinations forming the moſt power-

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theſe experiments, as alſo from the deduction which may be fairly made from the effects of batteries, we may conclude that every active Galvanic combination has a poſitive and a negative ſide. Hence it is ſuppoſed, that when the circle is completed, as in fig. 10, viz. by connecting the leather with the copper, a circulation of electric fluid takes place through it.

" If we form a metallic plate of two portions, the one of " zinc, the other of copper, by ſoldering their ends together, " and taking the zinc between our fingers, touch with the " copper the upper plate of the condenſer, which is alſo " of copper, the condenſer becomes negative. But if, on " the contrary, we hold the copper in our fingers, and touch " the upper plate of the condenſer with the zinc; upon re-" moving the metals and raiſing the upper plate of the con-" denſer, it indicates no electricity, notwithſtanding the " lower plate is connected with the common reſervoir in the " earth.

" But as ſoon as we interpoſe between the zinc and the " plate of the condenſer a piece of paper moiſtened with " pure water, or any other moiſt conductor, the condenſer " becomes charged with poſitive electricity. It becomes " alſo charged, but negatively, when we hold the zinc in " our fingers, and touch, with the copper, the humid con-" ductor laid on the condenſer." Report of the National Inſtitute at Paris, on Volta's Experiments made in the courſe of the year 1801.

ful

ful batteries, and *vice verſa)* provided the ſimple combinations are diſpoſed ſo as not to counteract each other.

Thoſe batteries are ſaid to be of the firſt or of the ſecond order, according as the ſimple combinations, of which they conſiſt, are of the firſt or of the ſecond order. Thus, if a piece of zinc be laid upon a piece of copper, and a piece of moiſtened card be laid upon the zinc; then a ſimilar arrangement of three other ſuch pieces be laid upon them, and a third arrangement be laid upon this, &c. all in the ſame order; the whole will form a battery of the firſt order. But if the arrangement be made by connecting a piece of copper with a piece of cloth moiſtened with water; the latter with a piece of cloth moiſtened with a ſolution of ſulphuret of potaſh, and this again with another piece of copper, &c. the whole will form a battery of the ſecond order*.

The

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* Mr. Davy diſtinguiſhes the batteries of the ſecond order into the following three claſſes:

I. The moſt feeble is compoſed, whenever ſingle metallic plates, or arcs, are arranged in ſuch a manner, that two of their ſurfaces, or ends oppoſite to each other, are in contact with different fluids, one capable and the other incapable of oxidating the metal. And regular ſeries of ſuch combinations are formed.

II. When the ſingle combinations or elements of the ſeries conſiſt each of a ſingle plate or arc of a metallic ſubſtance

The above-mentioned reſtriction, viz. that the parts of a battery muſt not counteract each other, will be eaſily underſtood by conſidering that every ſimple, but interrupted, Galvanic combination has a poſitive and a negative end; or that in every complete Galvanic circle, the electric fluid circulates in one way only. Thus, if two ſimple combinations be diſpoſed, as in fig. 11, this arrangement will not have any Galvanic power, becauſe the actions of the two ſimple combinations, or the two currents of electricity, are oppoſed to each other; the two poſitive ends being at *p*, and the two negative ends being at *n*. But if thoſe ſix bodies be diſpoſed as in fig. 12; then the combination will be very active; becauſe, according to the hypotheſis, the direction of the electric fluid in each ſimple arrangement tends the ſame way, and probably the one accelerates the other.

ſtance capable of acting upon ſulphurated hydrogen, or upon ſulphurets diſſolved in water, is accompanied with portions of a ſolution of ſulphuret of potaſh on one ſide, and water on the other.

III. The moſt powerful claſs is formed when metallic ſubſtances oxidable in acids, and capable of acting on ſolutions of ſulphurets, are connected, as plates, with oxidating fluids and ſolutions of ſulphuret of potaſh, in ſuch a manner that the oppoſite ſides of every plate may be undergoing different chemical changes, the mode of alternation being regular.

What

What has been ſaid above of the arrangement of two ſimple Galvanic combinations, muſt be likewiſe underſtood to hold good with reſpect to the connection of any number of the ſame; viz. that they muſt not counteract each other; or, if a certain number of them counteract each other, then the remaining only form the active part of the battery. For inſtance, if a battery conſiſt of 40 ſimple combinations, and if 12 of them are placed in a direction contrary to the others; then thoſe 12 will counteract 12 others, and of courſe the whole battery will have no more power than if it conſiſted of 16 ſimple combinations properly diſpoſed.

This points out a method of comparing the powers of two batteries; for if thoſe batteries be connected in an inverted order, viz. the poſitive end of one be made to touch the negative end of the other; then, on connecting the two other extremities, or on applying them to proper inſtruments, the whole power will be annihilated, if the ſeparate batteries had equal power; otherwiſe the power of the whole will be the exceſs of the power of the moſt powerful battery above that of the weakeſt; and the direction, viz. its being poſitive or negative, will ſhew to which battery it belongs. It muſt be obſerved, with reſpect to the inactive arrangement of fig. 11, that if one of the ſeparate bodies Z be removed, then the remaining five bodies will form an active combination; for in that caſe, W, W, become one body, and S, S, do likewiſe act as one body.

It is almoſt ſuperfluous to obſerve, that (as has been ſaid with reſpect to ſimple circles) in a Galvanic battery the interpoſition of conductors that have no particular action, or of the conductors of the ſame claſs as the adjoining bodies, does not alter the effect of the battery.

Thus far we have ſtated the general laws, which have been pretty well aſcertained with reſpect to Galvanic combinations. We ſhall now proceed to deſcribe the practical conſtruction, and the effects of thoſe combinations, eſpecially of the compound arrangements or batteries.

The ſimplicity of ſingle Galvanic circles is ſo great, that nothing more needs be ſaid with reſpect to their conſtruction; for when the three bodies are ſelected, the operator needs only take care that their contact be perfect.

Voltaic batteries have been conſtructed of various ſhapes, and they may be endleſsly diverſified. But the moſt uſual forms are repreſented by fig. 13, 14, and 16, Plate XXIV. Thoſe of fig. 13 and 14, are more eaſily conſtructed; that of fig. 16, is the moſt commodious.

The battery, fig. 13, conſiſts of ſeveral glaſſes, or china cups full of water, or of water containing ſalt, &c. and two plates unconnected with each other, viz. a plate of zinc and a plate of ſilver,

are

are plunged in the fluid of each cup, excepting the firſt and laſt cups; but each of thoſe plates muſt have a ſort of tail or prolongation, by which they are ſo connected that the ſilver plate of one cup communicates with the zinc plate of the next, and ſo on; thoſe prolongations being ſoldered at *a*, *a*, *a*, &c.

The battery, fig. 14, conſiſts of pieces of ſilver, about as big as half crowns, pieces of zinc, about equal to thoſe of ſilver, and pieces of card, or cloth, or leather, or other bibulous ſubſtance, a little ſmaller in diameter than the metallic pieces, and ſoaked in water or in other proper fluid.

Thoſe pieces are diſpoſed in the order of ſilver, zinc, and wet cloth, &c. as indicated by the letters S, Z, W. The pieces of card, or cloth, &c. muſt be well ſoaked in the fluid; but before they are applied, they ſhould be gently ſqueezed, in order that the ſuperfluous fluid may not run down the outſide of the pile, or inſinuate itſelf between the contiguous pieces of ſilver and zinc. Thoſe pieces, eſpecially if ſoaked in plain water, loſe their moiſture pretty ſoon, ſo that they can hardly ſerve longer than for a day or two; after which time the pile muſt be decompoſed, the metallic pieces cleaned, thoſe of cloth or card ſoaked again, and the whole arranged as before.

The three rods R, R, R, are of glaſs or of baked wood, and the piece of wood, O, ſlides freely up or or down the rods. This ſerves to prevent the falling of the pieces.

When ſuch battery is to be very powerful, viz. is to conſiſt of numerous pieces, the beſt way is to form two or three or more piles, and to join them by pieces of metal, as *c c* in fig. 15, where two piles are joined together, ſo that *a* is the negative extremity, and *b* is the other or poſitive extremity of the whole arrangement, or of the two piles conſidered as one.

The battery, fig. 16, conſiſts of a ſtrong oblong veſſel of baked wood, about three inches deep and about as much broad. In the ſides of this veſſel grooves are made oppoſite to each other, and about one-eighth of an inch in depth. In each pair of oppoſite grooves a double metallic plate, viz. a plate of zinc and a plate of ſilver ſoldered together at their edges, are cemented; by which means the wooden veſſel is divided into ſeveral partitions, or cells, about half an inch broad, as is ſufficiently indicated by the figure. The cementation of the metallic pieces into the ſides and the bottom of the wooden veſſel, muſt be ſo accurate as not to permit the paſſage of any fluid from one cell into the next. The cement proper for this purpoſe is deſcribed in page 381.

Thoſe cells are afterwards filled almoſt to the top with water, or any other fluid, according to the table in page 479; and thus the whole will form a Voltaic battery,

battery, conſiſting of various repetitions of ſilver, zinc, and fluid. Two or more of ſuch batteries may be joined, as has been ſaid of the preceding battery.

I need hardly obſerve, that inſtead of zinc copper and water, other combinations may be made according to the table in page 479. At preſent the laſt deſcribed batteries are conſtructed with copper, zinc, and water mixed with a ſmall proportion of nitric or muriatic acid. For the conſtruction of ſuch batteries it is immaterial whether the metals are quite pure or ſlightly alloyed.

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The action of all thoſe batteries is greateſt when they are firſt completed or filled with the fluid; and it declines in proportion as the metal is oxidated, or the fluid loſes its power. Hence, after a certain time, not only the fluid muſt be changed, but the metallic pieces muſt be cleaned by removing the oxidated ſurface, which is done either by filing or by rubbing them with ſand or ſand-paper, or by immerſing them for a ſhort time in diluted muriatic acid, and then wiping them with a coarſe cloth. The metallic pieces of the battery, fig. 16, may be cleaned by the laſt method, and may be wiped by introducing a ſtick with a rag into the cells.

Thus much may be ſufficient with reſpect to the conſtruction of ſimple and compound Galvanic arrangements. It is now neceſſary to ſtate the effects of thoſe combinations. Indeed the mode of applying ſingle Galvanic circles and their principal effects, have already been deſcribed; yet, for the ſake of aſſiſting the memory, it will be uſeful to collect thoſe effects under the four following heads, in explanation of which we ſhall add ſuch farther experiments and obſervations as could not with propriety be mentioned before.

I. The action of a ſingle Galvanic circle affects the organs of living animals, or of animals recently dead, eſpecially when one end of the combination is connected with a nerve, and the other end is connected with a muſcle of the ſame limb.

II. That action may be tranſmitted through good conductors of electricity, but not through electrics, or through leſs perfect conductors.

III. It affects the electrometer by the intermediation of other inſtruments.

IV. That action increaſes, or otherwiſe modifies, the chemical agency of the bodies concerned, upon each other.

The limbs of animals, eſpecially of frogs recently dead, are the moſt ſenſible inſtruments of Galvanic powers; and, in fact, the ſimpleſt Galvanic circles will affect them, when they will not produce any other deciſive electrical effect.

The various powers of different ſimple circles may be aſcertained by applying them to ſuch animal preparations as have their vitality, or irritability, more or leſs exhauſted. Thus Mr. Volta in his letter to Gren, ſays, " If you take a frog, the

" head

"head of which has been cut off, and which has "been deprived of all life by thruſting a needle "into the ſpinal marrow, and immerſe it without "ſkinning, taking out the bowels, or any other "preparation, into two glaſſes of water; the rump "into one, and the legs into the other, as uſual; it "will be ſtrongly agitated and violently convulſed, "when you connect the water in both glaſſes by a "bow formed of two very different metals, ſuch as "ſilver and lead, or, what is better, ſilver and "zinc; but this will by no means be the caſe when "the two metals are leſs different in regard to their "powers, ſuch as gold and ſilver, ſilver and copper, copper and iron, tin and lead. But what is "more, the effect will be fully produced on this ſo "little prepared frog, when you immerſe in one of "the two glaſſes the end of a bow merely of tin or "zinc, and into the other glaſs the other end of "this bow which has been rubbed over with a little "alkali. You may perform the experiment ſtill "better with an iron bow, one end of which has "been covered with a drop or thin coating of nitrous acid; and beyond all expectation, when you "take a ſilver bow, having a little ſulphuret of potaſh adhering to its extremity."

When a ſingle powerful Galvanic combination of the ſecond order is applied with one end to the tongue, and with the other fluid end to ſome other ſenſible part of the body, an acid taſte is perceived on the tongue, which taſte, by continuing the contact,

contact, becomes leſs diſtinct, and is even changed into an alkaline taſte.

"If a tin baſon be filled with ſoap-ſuds, lime-"water, or a ſtrong ley, which is ſtill better; and if "you then lay hold of the baſon with both your "hands, having firſt moiſtened them with pure "water, and apply the tip of your tongue to the "fluid in the baſon, you will immediately be ſen"ſible of an acid taſte upon your tongue, which is "in contact with the alkaline liquor. This taſte is "very perceptible, and, for the moment, pretty "ſtrong; but it is changed afterwards into a dif"ferent one, leſs acid, but more ſaline and pungent, "until at laſt it becomes alkaline and ſharp, in "proportion as the fluid acts more upon the "tongue*."

Mr. Davy obſerves, that "if zinc and ſilver be "made to form a circle with diſtilled water, hold"ing in ſolution air, for many weeks, a conſidera"ble oxidation of the zinc is perceived, without "the perceptible evolution of gaſs; and the water, "at its point of contact with the ſilver, becomes "poſſeſſed of the power of tinging green, red cab"bage juice, and of rendering turbid, ſolution of "muriate of magneſia."

The chemical action of bodies upon each other is increaſed by the Galvanic arrangement, ſo much, that ſome of them are thereby enabled to act upon

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* Volta's Letter to Gren.

bodies that otherwiſe they would have no action upon. Fig. 17, Plate XXIV. repreſents a glaſs tube about four inches long. Two corks are thruſt into its apertures A and B. An oblong piece of zinc, CD, is fixed into one of the corks, and is made to project within and without the tube. EFG is a ſilver wire, which, being fixed into the other cork, projects with the extremity E within the tube; and its other extremity is bent ſo as to come near the projecting part of the zinc C.

Remove one of thoſe corks, and fill the tube with water, in which you muſt mix a drop or two of muriatic acid; then replace the cork, and you will find that the zinc is acted upon by the diluted acid; is oxidated by it, and bubbles of gas are evolved from it; but the ſilver wire E remains untouched, and no gas whatever is evolved from it. Now, if you bend the ſilver wire FG, ſo that its end G may touch the zinc at C, then the Galvanic circle of ſilver, zinc, and diluted acid is completed, in conſequence of which the diluted acid is enabled to act ſtronger upon the zinc D, which is manifeſted by the more copious evolution of gas, and is, beſides, enabled to act upon the ſilver wire; for now you will obſerve the evolution of gas from the ſilver E alſo.—Break the contact between G and C, and the ſilver E will ceaſe to yield gas.—Form it again, and gas will again proceed from the ſilver.

Inſtead of ſilver, zinc, and diluted muriatic acid, you may in the ſame manner uſe gold, tin, and diluted

luted nitric acid; and by completing the circle, the acid will be enabled to act upon the gold.

It has been obſerved, that whenever an oxidating influence is exerted at one of the places of contact of the perfect and imperfect conductors, a deoxidating action appears to be produced at the other place. Thus when iron, which oxidates rapidly when forming a circle with ſilver and common water, is arranged with zinc and common water, it remains perfectly unaltered, whilſt the zinc is rapidly acted upon *.

Such are the facts which have as yet been diſcovered with reſpect to the power of ſingle Galvanic circles. They form a remarkable addition to the ſcience of electricity, and open a vaſt field of ſpeculation and experimental inveſtigation; yet we are unable to form a theory ſufficient to account for the original cauſe, or for the action of that very remarkable power; and we can only wait with patience for the probable elucidation, which may be afforded by farther diſcoveries.

If the effects of ſingle circles are very remarkable, the collected power of ſeveral ſingle circles, or of the Voltaic battery, cannot fail of ſurpriſing the leaſt reflecting mind.

The Voltaic battery not only convulſes the prepared limbs of a frog, or produces the appearance of a flaſh of light before the human eye; but it

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* Journals of the Royal Inſtitution, N° 4.

ſhews all the phenomena of electricity in a very conſiderable degree. It gives the ſhock; it affects the electrometer; ſhews a luminous ſpark, accompanied with an audible report; it burns metallic, and other combuſtible bodies; and continues in action for a very long time, viz. until the chemical action between the component parts of the battery is quite exhauſted.—The following paragraphs contain a more particular, yet conciſe, enumeration of thoſe wonderful effects.

When Volta's battery of the firſt order (the action of thoſe of the ſecond order being weaker and much more tranſient) conſiſts of 20 repetitions of ſimple combinations, if you touch with one hand one extremity of the battery, as at *b*, in any one of the above-deſcribed batteries, and apply your other hand to the other extremity of the battery, as at *a*; you will feel a very ſlight ſhock, like that which is communicated by a Leyden phial weakly charged, and it will be hardly felt beyond the fingers, or at moſt the wriſts. This ſhock is felt as often as you renew the contact. If you continue the hands in contact with the extremities *b* and *a*, you will perceive a ſlight but continuate irritation; and, when the hand or other part of the body, which touches the extremity of the battery, is excoriated or wounded, this ſenſation is diſagreeable and rather painful.

The dry ſkin of the human body is ſeldom capable of conducting this ſhock; therefore the touching fingers ſhould be well moiſtened with water. It will be better to immerſe a wire, that proceeds from one extremity of the battery, in a baſon of water, wherein you may plunge one of your hands; then graſping with your other hand well moiſtened, a large piece of metal, for inſtance, a large ſilver ſpoon, touch the other end of the battery with it, and the ſhock will be felt more diſtinctly. By this means the ſhock has been felt when the battery conſiſted of leſs than 20 repetitions.

Inſtead of one perſon, ſeveral perſons may join hands, (which muſt be well moiſtened with water) and on completing the circuit, they will all feel the ſhock at the ſame inſtant. But the ſtrength of the ſhock is much diminiſhed by its paſſing through the ſeveral perſons, or, in general, by paſſing through leſs perfect conductors.

The ſhock from a battery conſiſting of 50 or 60 repetitions of the moſt active combinations of the firſt order may be felt as far as the elbows; and the combined force of 5 or 6 ſuch batteries will give a ſhock perhaps much ſtronger than moſt men would be willing to receive. The prepared limbs of a frog or other animal are violently convulſed, but ſoon exhauſted of their irritability, by the action of a Voltaic battery.

This ſhock is ſimilar to that of a large common electrical battery weakly charged, and not to that of a ſmall Leyden phial fully charged. The difference conſiſts in this, viz. that the latter contains a ſmall quantity of electric fluid highly condenſed; hence its diſcharge will force its way through perhaps an inch of air; whereas the former contains a vaſt quantity of electricity, but little condenſed; hence its ſpark, viz. its courſe through the air, is ſo very ſhort, that the fingers muſt be brought almoſt into perfect contact in order to receive the ſhock; and ſuch is the caſe with the Voltaic battery; for the ſhock from a very powerful battery of this ſort will hardly ever force its way through the air, when the extremities of the circle of communication are more than a fortieth of an inch diſtant, even when thoſe extremities conſiſt of perfect conductors. In this caſe a ſmall but very vivid ſpark is ſeen at that extremity, accompanied with an audible but not ſtrong report. There is no perceptible difference of appearance between the ſpark of the poſitive and that of the negative end of the battery.

If a wire proceeding from one extremity of a pretty ſtrong Voltaic battery be made to communicate with the inſide coating, and a wire, which proceeds from the other extremity of the Voltaic battery, be made to communicate with the outſide coating of a common large jar or electrical battery; the latter will thereby become *weakly*, but almoſt *inſtantaneouſly*, charged, in the ſame manner as if it had been charged by a few turns of a common electrical machine; and with that charge you may either give the ſhock, or affect on electrometer, &c.

In ſhort, every thing conſpires to prove that a Voltaic battery produces a vaſt quantity of electric

fluid,

fluid, but which is little condenſed; and indeed it would be impoſſible to ſuppoſe, that the electric fluid could proceed in a very condenſed ſtate from an arrangement of bodies, which, whether more or leſs, are, however, all good conductors of electricity; for if the fluid were much condenſed at one extremity of the Voltaic battery, and much rarefied at the other extremity, the compenſation would ſoon be made through the pile itſelf. Indeed it is difficult to comprehend how this compenſation does not take place in all caſes.

The electric fluid may probably be a neceſſary ingredient in the compoſition of bodies; and perhaps the chemical action of one body upon another diſengages from the latter the electric fluid, as it diſengages the caloric in ſeveral caſes: but the queſtion is, why the electric fluid, which is extricated from the bodies of a Voltaic battery, is forced to move one way; and why is the other extremity of the battery in a negative ſtate of electricity?

Thoſe doubts may perhaps be cleared by future diſcoveries; but let us return to the ſtatement of facts.

Having mentioned above, that the charge of a Voltaic battery may be communicated to a common electrical battery; it is almoſt ſuperfluous to obſerve, that the ſame may be communicated to a condenſer, or to my multiplier, and from it to the electrometer. If the Voltaic battery conſiſt of 200 repetitions, the electrometer will be affected by the ſimple contact.

The

The ſpark, or the diſcharge of a Voltaic battery, when ſent through thin inflammable bodies that are in contact with common or oxygen air, ſets them on fire, and conſumes them with wonderful activity. It fires gun-powder, hydrogen gas, phoſphorus, and other combuſtibles; it renders red-hot, fuſes, and conſumes very ſlender metallic wires and metallic leaves. The mode of applying the power of the battery for ſuch purpoſes, is ſhewn in fig. 18, Plate XXIV. where A B repreſents a powerful Voltaic battery; ACDF is a wire which communicates with the laſt plate of the battery at A; B K I H G is another wire which communicates with the laſt plate at B. D E, H I, are two glaſs tubes, through which thoſe wires paſs, and into which they are faſtened ſufficiently ſteady. Thoſe tubes ſerve to move the wires by; for if the operator apply his fingers to the middlemoſt parts of thoſe tubes, he may move the wires wherever he pleaſes, without the fear of receiving a ſhock. If the two extremities F, G, be brought ſufficiently near to each other, the ſpark will be ſeen between them. It is between thoſe extremities that the combuſtible ſubſtances, or metallic leaf, &c. is to be placed, in order to be fired or conſumed. This figure repreſents the ſituation of the wires in the act of inflaming gun-powder*.

Under

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* A battery conſiſting of 200 pairs of metallic plates (viz. copper and zinc, each 5 inches ſquare) melted 23 inches

Under the exhauſted receiver of the air-pump, the Voltaic battery acts leſs powerfully than in the open air; but in oxygen air it acts with increaſed power.

The flaſh of light which appears before the eye of the experimenter, when the eye itſelf, or ſome other part not very remote from it, is put in the circuit of a Galvanic combination, does not appear much greater when a battery is employed, than when two plates are applied in the manner which has been already mentioned; but when the battery is uſed, the ſenſation of a flaſh may be produced in various ways. If one hand or both be placed in perfect contact with one extremity of the battery, and almoſt any part of the face be brought into contact with the other extremity of the battery, the flaſh will appear very diſtinctly; the experimenter being in the dark, or keeping his eyes ſhut. This flaſh appears very ſtrong, when a wire which proceeds from one extremity of the battery is held between the teeth, and reſts upon the tongue, whilſt the other wire is held in the hand. In this caſe the lips and the tongue are convulſed, the flaſh appears before the eyes, and a very pungent taſte is perceived in the mouth.

If any part of the human body, forming part of the circuit of a Voltaic battery, be kept ſometime in that

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inches of very fine iron wire. A platina wire about $\frac{1}{175}$ inch in diameter, was melted into a globule.

ſituation, the irritation or numbneſs is more or leſs diſtinct, and more or leſs painful, according to the ſenſibility of the parts concerned. This application is likely to prove moſt uſeful as a remedy in various diſorders. It is ſaid that it has already proved beneficial in deafneſſes and in rheumatiſms. It highly deſerves to be tried by medical perſons.

The moſt extraordinary phenomena of a Voltaic battery are the chemical effects, and the modifications which are produced by it upon the bodies concerned, or upon ſuch as are placed in the circuit. I ſhall firſt deſcribe the ſimpleſt mode of exhibiting the principal of thoſe phenomena; namely, the evolution of gas from water; from which the mode of conducting ſimilar experiments is eaſily derived; then ſhall tranſcribe the various particulars which relate to thoſe chemical effects, from the Journals of the Britiſh Royal Inſtitution, where they are conciſely expreſſed; and to which I ſhall add notes with farther illuſtrations.

A B, Fig. 19, Plate XXIV. exhibits a glaſs tube full of diſtilled water, and having a cork at each extremity. E F is a braſs or copper wire, which proceeds from one extremity of a Voltaic battery, and, paſſing through the cork A, projects within the tube. H G is a ſimilar wire, which proceeds from the other extremity of the battery, and comes with its extremity G within the diſtance of about an inch or two from the wire F.

In this ſituation of things, you will find that bubbles of gas proceed in a conſtant ſtream from the ſurface G of the wire which proceeds from the negative end of the battery; theſe bubbles of gas, aſcending to the upper part of the tube, accumulate by degrees. This gas is the hydrogen, and may be inflamed. At the ſame time the other wire F depoſits a ſtream of oxide in the form of a ſteam or cloud, which gradually accumulates in a greeniſh form in the water, or on the ſides of the tube, and is a perfect oxide of the braſs. The wire F is readily diſcoloured and corroded. If you interrupt the circuit, the production of gas and of oxide ceaſes immediately.—Complete the circuit, and the production of gas reappears, &c.

This production of gas may be obſerved even where the battery conſiſts of not more than ſix or eight repetitions of ſilver, zinc, and water. In ſhort, if the power of the battery be ſufficient to oxidate one of the wires of communication, the other wire will afford hydrogen gas; both extremities of the wires being in water*.

In

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* In this experiment it ſeems that the hydrogen is ſeparated from the water, and is converted into a gaſeous ſtate by the wire connected with the negative extremity of the battery; whilſt the oxygen unites with and oxidates the wire connected with the poſitive end of the battery. If you connect the poſitive end of the battery with the lower wire of the tube, and the negative with the upper; then the hydrogen proceeds

In the above deſcribed apparatus, a little hole muſt be made in the lower cork B, for the purpoſe of giving exit to the water in proportion as the gas is formed.

" In all batteries of the firſt order, when the con-
" nexion is completed, changes take place which
" denote the evolution of influences capable of pro-
" ducing from *common* water, oxygene and hydro-
" gene, acid and alkali, in different parts of the
" ſeries.

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proceeds from the upper wire, and the lower wire is oxidated.

If two wires of gold or platina be uſed, which are not oxidable; then the ſtream of gas iſſues from each, the water is diminiſhed, and the collected gas is found to be a mixture of hydrogen and oxygen. It explodes violently.

Thoſe two different elaſtic fluids may be obtained ſeparate from each other by the following means. Let the extremities of the two wires, which proceed from the battery, be immerſed in water, at the diſtance of about an inch from each other, and place over each of them a ſmall glaſs veſſel inverted and full of water, as in fig. 20, Plate XXIV. However, Dr. Prieſtley, who denies the convertibility of water into hydrogen and oxygen air, thinks that the elaſtic fluid in theſe experiments originates from the air which is contained in the water; "ſince," ſays he, "if by means of oil upon the water, or a vacuum, acceſs to the atmoſphere be cut off, the whole production of gas ceaſes." Nor is any air produced when the water has been exhauſted of it. See Nicholſon's Journal of Natural Philoſophy for March 1802, page 198.

" Thus

“ Thus in the battery with ſeries of zinc plates, “ ſilver wires, and common water, oxide of zinc is “ formed on all the plates of zinc, whilſt hydrogen “ is produced from the ſilver wires; and if the water “ in contact with them be tinged with red cabbage “ juice, it becomes green.

“ And in the battery with ſilver, gold, and weak “ nitric acid, the ſilver is diſſolved, whilſt the acid “ becomes green, and ſlowly evolves gas at its points “ of contact with the gold.

“ The chemical agencies exerted in the com- “ pound batteries of the firſt order can be beſt ob- “ ſerved by the ſubſtitution of ſingle metallic wires “ for ſome of the double plates; for, in this caſe, “ the changes taking place in the ſeries with wires, “ will be exactly analogous to thoſe produced in “ the ſeries with plates; ſilver, and all the more “ oxidable metals, oxydating in water, in the uſual “ place; and gold and platina evolving oxygene “ gas.

“ Thus, when into two ſmall glaſs tubes, con- “ nected by moiſt animal ſubſtance, and filled with “ diſtilled water, two gold wires are introduced from “ a large battery, in the proper order, oxygene is “ produced in one quantity of water, and hydrogen “ in the other, nearly in the proportions in which “ they are required to form water by combuſtion: “ and if the proceſs be continued for ſome time, the “ apparatus being expoſed to the atmoſphere, the “ water, in the oxygene-giving tube, will become

" impregnated with an acid (apparently the nitrous); whilſt that in the hydrogen-giving tube " will be found to hold in ſolution an alkali, which, " in certain caſes, has appeared to be fixed.

" From ſome experiments it would appear probable that the quantities of hydrogene, produced " in ſeries, are ſmall, and the quantities of alkali " great, in proportion as the ſurfaces of contact of " the leaſt oxidable metals with the water are more " extended.

" All the oxygenated ſolutions of bodies poſſeſſing " leſs affinity for oxygene than naſcent hydrogene, " are decompoſed when expoſed to the action of " the metal occupying the place of the leaſt oxidable part of the ſeries in the compound circle.

" Thus, ſulphur may be produced from ſulphuric acid; and copper and other metals precipitated in the metallic form from their ſolvents *.

" But

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* " It is well known that hydrogen gas, in its naſcent ſtate, reduces the oxydes of metals. Accordingly, when the tube, fig. 19, is filled with a ſolution of acetite of lead in diſtilled water, and a communication is made with the battery as above deſcribed, no gas is perceived to iſſue from the wire which proceeds from the negative end of the battery; but, in a few minutes, beautiful metallic needles are perceived on the extremity of this wire; theſe ſoon increaſe, and aſſume the form of a fern, or other vegetable. The lead thus ſeparated is in its perfect metallic ſtate, and very brilliant.

" When

"But little knowledge has yet been obtained "concerning the chemical changes taking place in "the batteries of the ſecond order. But from ſeveral experiments it would appear that they are "materially different in the laws of their production from thoſe taking place in the firſt "order.

"Thus, when ſingle metallic wires with water "are placed as ſeries in powerful batteries of the "ſecond order, the influence producing oxygene "ſeems to be tranſmitted by the point, in the "place of that part of the plate, which was apparently incapable of undregoing oxidation; whilſt

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"When a ſolution of ſulphat of copper is employed, the copper is precipitated in its metallic ſtate; but inſtead of appearing in cryſtals, it forms a kind of button, which adheres firmly to the end of the wire.

"On making the experiment with a ſolution of nitrate of ſilver, the ſilver is precipitated in the form of a beautiful metallic bruſh, the metal ſhooting into fine needle-like cryſtals." Garnett's Annals of Philoſophy, vol. I. p. 19.

If a piece of iron be immerſed in a ſolution of ſulphat of copper, the latter metal will be precipitated in a metallic form, and will adhere to the ſurface of the former. Upon ſilver merely immerſed in the ſame ſolution, no ſuch effect is produced; but as ſoon as the two metals, viz. the ſilver and the copper, are brought into contact, the ſilver receives a coating of copper. Phil. Tranſ. for the year 1801. Wollaſton's Paper, p. 428.

" the hydrogen is evolved from that point, where " the oxidating part of the primary ſeries appeared " to exiſt.

" The agency of the Galvanic influence, which " occaſions chemical changes, and communicates " electrical charges, is probably, in ſome meaſure, " diſtinct from that agency which produces ſparks, " and the combuſtion of bodies.

" The one appears (all other circumſtances being ſimilar) to have little relation to ſurface in " compound circles, but to be great, in ſome unknown proportion, as the number of ſeries are " numerous. The intenſity of the other ſeems to " be as much connected with the extenſion of the " ſurfaces of the ſeries, as with their number*.

" Thus, though eight ſeries compoſed of plates of " zinc and copper, about 10 inches ſquare, and of " cloths of the ſame ſize, moiſtened in diluted muriatic acid, give ſparks ſo vivid as to burn iron wire; " yet the ſhocks they produce are hardly ſenſible, " and the chemical changes indiſtinct; whilſt 24 " ſeries of ſimilar plates and cloths, about 2 inches

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* Van Marum obſerved, that the intenſities of two columns containing an equal number of plates, appeared equal by the electrometer, although their diameters were ſo different as one and five inches. On taking ſhocks from both batteries, their powers alſo ſeemed to be equal. In the fuſion of wire, however, the large diameter had an evident advantage.

" ſquare, which occaſion ſhocks and chemical " agencies more than three times as intenſe, pro- " duce no light whatever.

" A meaſure of the intenſity of the power in " Galvanic batteries, producing chemical changes, " may be derived from the quantity of gas it is ca- " pable of evolving from water in a given time."

The preceding facts can hardly leave any doubt with reſpect to the identity of the Galvanic power, and the electricity which is produced by means of a common electrical machine, or that is brought down from the clouds; but, what is ſtill more remarkable, it reconciles to the ſame principle the animal electricity, viz. the power of the torpedo, gymnotus electricus, &c. ſince all the phenomena of the animal electricity agree with thoſe of the Voltaic battery.

The electrical fiſhes give the ſhock in water; and in the ſame manner, if the ends of the wires, which proceed from the extremities of the Voltaic battery, be immerſed both in the ſame baſon of water, at ſome diſtance from each other; and if you plunge your hands in the ſame water, you will receive the ſhock, the greateſt part of which will paſs, not through the water, but through your body, which is the better conductor of the two.

The ſtrongeſt ſhock of the gymnotus will hardly at all paſs through any interruption of circuit, and ſuch is alſo the caſe with the Voltaic battery.

But the moſt ſtriking circumſtance is, that the electric

electric organ of any of the above-mentioned fiſhes ſeems to be conſtructed exactly like a Voltaic battery; for it conſiſts of little laminæ or pellicles arranged in columns, and ſeparated by moiſture *. It ſeems, in ſhort, to be a Voltaic battery, conſiſting of conductors of the ſecond order only; but undoubtedly of different conducting powers.

Though the Voltaic battery exhibits all the leading properties of common electricity, ſuch as the attraction, the ſpark, &c. yet in ſome effects, viz. the decompoſition of water, oxygenation of metals, &c. the former ſeemed to differ conſiderably from the latter; but thoſe apparent differences have been ſufficiently reconciled by ſome very ingenious experiments and obſervations of Dr. W. H. Wollaſton †.

With reſpect to the decompoſition of water, which was thought to require very powerful electrical machines, he juſtly ſuſpected, that by reducing the ſurface of communication, the decompoſition of water might be effected with leſs powerful means; and this was verified by actual experiments. "Having, "*he ſays*, procured a ſmall wire of fine gold, and "given it as fine a point as I could, I inſerted "it into a capillary glaſs tube; and after heating

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* See Hunter's Papers on the Torpedo and Gymnotus, Phil. Tranſ. vol. 63 and 75.

† See his valuable Paper in the Phil. Tranſ. for 1801, Article XXII.

the tube ſo as to make it adhere to the point, and cover it in every part, I gradually ground it down, till, with a pocket-lens, I could diſcern that the point of the gold was expoſed.

" The ſucceſs of this method exceeding my expectations, I coated ſeveral wires in the ſame manner, and found, that when ſparks from the conductors were made to paſs through water, by means of a point ſo guarded, a ſpark paſſing to the diſtance of $\frac{1}{8}$ of an inch would decompoſe water, when the point expoſed did not exceed $\frac{1}{700}$ of an inch in diameter. With another point which I eſtimated at $\frac{1}{1500}$ of an inch, a ſucceſſion of ſparks $\frac{1}{20}$ of an inch in length, afforded a current of ſmall bubbles of air.

" I have ſince found, that the ſame apparatus will decompoſe water, with a wire $\frac{1}{40}$ of an inch diameter, coated in the manner before deſcribed, if the ſpark from the prime conductor paſſes to the diſtance of $\frac{4}{10}$ of an inch of air."

He alſo found, that with a gold point ſimilar to, but much ſmaller than any of the above-mentioned, and ſimilarly ſituated in water, the mere current of electricity, without any ſparks, would occaſion a ſtream of very ſmall bubbles to riſe from the extremity of the gold.

" Having coloured a card with a ſtrong infuſion of litmus, I paſſed a current of electric ſparks along it, by means of two fine gold points, touching it at the diſtance of an inch from each other. The

" effect, as in other caſes, depending on the ſmall-
" neſs of the quantity of water, was moſt diſcernible
" when the card was nearly dry. In this ſtate, a
" very few turns of the machine were ſufficient to
" occaſion a redneſs at the poſitive wire, very ma-
" nifeſt to the naked eye. The negative wire, being
" afterwards placed on the ſame ſpot, ſoon reſtored
" it to its original blue colour."

Dr. Wollaſton likewiſe remarks another ſtrong point of analogy between the electricity of the Voltaic battery and that of a common electrical machine; viz. that they both ſeem to depend upon oxidation. In fact, a common electrical machine will act more or leſs powerfully, according as the amalgam which is applied to its rubber conſiſts of metals that are more or leſs oxidable.

I ſhall not proceed to conjecture in what manner the oxidation of metallic ſubſtance can furniſh electricity, nor ſhall I detain my reader any longer with hypotheſes concerning Galvaniſm; a ſubject of recent diſcovery, of extenſive influence, and which ſeems promiſing of ample recompenſe to the induſtry of diligent experimenters; but which is ſtill involved in much doubt and obſcurity.

SECTION IV.

ON MAGNETISM.

AN hard mineral body, of a dark grey, or dark brown, and ſometimes almoſt black colour, has been called a *natural magnet*, or *load-ſtone*. This mineral, which is an iron ore, has, from time immemorial, juſtly attracted the attention of mankind, on account of the very remarkable, and very uſeful, properties, of which it is found naturally poſſeſſed, and which are thence denominated *magnetic properties* *.

The magnetic properties may alſo be communicated to other ferruginous bodies by proper methods;

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* The word *magnet* is, by ſome ancient writers, derived from the name of a ſhepherd, by whom they ſuppoſe the magnet to have been firſt diſcovered on Mount Ida. It was in ancient times more commonly called *ſiderites*, from its property of attracting iron, which metal is called *σίδηρος*, in Greek; or *lapis heracleus*, by Pythagoras, Ariſtotle, Euripides, and others, from Heraclea, a city of Magneſia in ancient Lydia, where it was ſuppoſed to have been firſt found. It has alſo in later times been called *lapis nauticus*, from its uſe in navigation.

ſo that thoſe bodies will afterwards act exactly like natural magnets; hence the latter are called *artificial magnets*. But the magnetic properties do not ſeem to have any decided agency upon any other ſubſtance, beſides iron[*]; therefore the magnets, whether natural or artificial, and the bodies, upon which they act, are either iron in its pure ſtate, or ſuch compound bodies as contain iron. At leaſt the exceptions are rather equivocal.

A magnet, whether natural or artificial, is always poſſeſſed of the following characteriſtic properties, which are inſeparable from its nature; ſo that a body cannot be called a magnet, unleſs it be poſſeſſed of all thoſe properties at the ſame time; neither was there a magnet ever produced which had one only or a few of thoſe properties[†]:

1. A magnet attracts iron and other ferruginous bodies.

2. When a magnet is placed ſo as to be at liberty to move itſelf with ſufficient freedom, as if it be ſuſpended by a thread, &c. it turns one, and conſtantly the ſame, part of its ſurface towards the north pole of the earth, or towards a point not much

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[*] The few and trifling exceptions to this general law will be noticed in the ſequel.

[†] In the firſt volume of the Philoſophical Magazine, page 426, it is ſaid that the ſerpentine of Humboldt has ſome of the magnetic properties only; but the account is imperfect, and, in all probability, incorrect.

much diſtant from it; and of courſe it turns the oppoſite part of its ſurface towards the ſouth pole of the earth, or towards a point not much diſtant from it. Thoſe parts on the ſurface of the magnet are therefore called its *poles*; the former being denominated its *north pole*, and the latter its *ſouth pole*. This property itſelf is called *the magnet's directive power*, or *the magnetic polarity*; and when a magnetic body places itſelf in that direction, it is ſaid to *traverſe*. A plain perpendicular to the horizon, and paſſing through the poles of a magnet when ſtanding in their natural direction, is called the *magnetic meridian*, and the angle which the magnetic meridian makes with the meridian of the place where the magnet ſtands, is called the *declination of the magnet*, or more commonly *of the magnetic needle* at that place; becauſe the artificial magnets, moſtly uſed for obſerving this property, are generally made of a ſlender ſhape; and ſometimes real ſewing needles, rendered magnetic, are uſed for this purpoſe.

3. When two magnets are placed ſo that the north pole of one of them is oppoſite to the ſouth pole of the other, then they attract each other; but if the ſouth pole of one magnet be placed oppoſite to the ſouth pole of the other, or if the north pole of the one be brought near the north pole of the other; in either caſe a repulſion takes place. In ſhort, magnetic poles of the ſame name repel each other; but thoſe of different names attract each other.

4. When a magnet is ſituated ſo as to be at liberty

berty to move itſelf with ſufficient freedom, it generally inclines one of its poles towards the horizon, and of courſe it elevates the other pole above it. This is called *the inclination*, or *dipping of the magnet*, or *of the magnetic needle.*

5. Any magnet may, by proper methods, be made to impart thoſe properties to iron, or to ſteel, or, in ſhort, to moſt ferruginous bodies.

The particular laws which have been aſcertained with reſpect to thoſe properties, their uſes, and the inſtruments neceſſary for thoſe purpoſes, will be deſcribed in the following chapters.

CHAPTER I.

OF MAGNETIC ATTRACTION, AND REPULSION.

A Piece of iron or ſteel, or other ferruginous ſubſtance, ſufficiently ſmall, being brought within a certain diſtance of one of the poles of a magnet, (be it artificial or natural) is attracted by it, ſo as to adhere to the magnet, and not ſuffer to be ſeparated without an evident effort.

This attraction is mutual; viz. the iron attracts the magnet as much as the magnet attracts the iron; for if the magnet and the iron be placed upon two ſeparate pieces of cork or wood, to float upon water at ſome diſtance from each other, it will be found that the iron advances towards the magnet, as well as the magnet advances towards the iron; or if the iron be kept ſteady, the magnet will move towards it.

The force or degree of magnetic attraction varies according to different circumſtances; viz. a magnet attracts a piece of ſoft and clean iron more forcibly than any other ferruginous body of the like ſhape and weight, eſpecially ſuch as are of a harder nature. Thus hard ſteel or hard iron ores are attracted leſs forcibly than ſoft ſteel, and the latter leſs forcibly than iron. Oxygenated iron is attracted leſs forcibly in proportion as it is combined with more oxygen.

If the piece of iron be preſented ſucceſſively to the various parts of the ſurface of a magnet, it will be found that the attraction is ſtrongeſt at the poles of the magnet; that it diminiſhes in proportion as the part of the ſurface is more diſtant from the poles; and that it is hardly perceivable at thoſe parts which are equidiſtant from the poles of the magnet.

The attraction is ſtrongeſt near the ſurface of the magnet, and diminiſhes as the diſtance increaſes; viz. if a piece of iron be placed in contact with one of the poles of a magnet ſufficiently ſtrong, they will adhere to each other, and a certain degree of force is required to ſeparate them; but if the ſame piece of iron be kept at a certain diſtance from the ſame pole of the magnet, there will alſo be perceived an endeavour to attract it; but the force neceſſary to prevent that attraction, will be found much leſs than that which, in the preceding caſe, was found neceſſary to ſeparate them; and by increaſing the diſtance the attractive force will be found to diminiſh. Now it is very remarkable that the law of this diminution of the attractive force has not yet been aſcertained, notwithſtanding a vaſt number of experiments which have been made expreſsly for the purpoſe. Some philoſophers have found it to decreaſe in proportion to the ſquares of the diſtances, others in proportion to the cubes of the diſtances, and others again have found it to decreaſe according to one ratio within a certain diſtance, and according to another ratio beyond that diſtance. This difference of reſults ariſes from the various powers and ſhapes both of the magnets and of the iron; for as the attraction of the whole ariſes from the attraction of the parts, it naturally follows that if you gradually remove a piece of iron from the magnet, the diſtances between the neareſt parts may increaſe in one ratio, whilſt the diſtances between other parts will increaſe in another ratio, and by changing the magnets, or the ſhapes of the iron, thoſe ratios muſt neceſſarily be changed.—The only thing we can ſay reſpecting this decreaſe is, that the attractive force decreaſes faſter than the ſimple ratio of the diſtances*.

There is a limit in the ſhape and weight of the iron which may be moſt forcibly attracted by a given magnet; viz. more forcibly than a ſmaller or larger, a more or leſs, extended piece of iron; but this limit can only be determined by actual experiments. A ſingle piece of iron is attracted more forcibly than if it be divided into ſeveral parts, and all thoſe parts be preſented to the ſame magnet.

The attraction between the different poles of two

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* Such experiments are made by faſtening a magnet to one arm of a balance, by placing the iron at different diſtances below the magnet, and by counterpoiſing the attraction with weights in the oppoſite ſcale of the balance.

magnets has been found to begin from a greater diſtance, but to be leſs powerful when in contact, than between ſoft iron and a magnet.

Magnetic repulſion takes place only between ſimilar poles of different magnets. Thus, if the north pole of one magnet be oppoſed to the north pole of another magnet; or if the ſouth pole be oppoſed to the ſouth pole, then thoſe magnets will repel each other, and that nearly with as much force as the poles of different names would attract each other *. But it frequently happens, that though magnets are placed with their like poles towards each other, yet they either attract each other, or ſhew a perfect indifference. Theſe phenomena ſeem to contradict the above-mentioned general law; but the following facts will remove the difficulty:

When a piece of iron, or of any other ſubſtance that contains iron, is brought within a certain diſtance of a magnet, it becomes itſelf a magnet, having the poles, the attractive and repulſive properties, &c. like another magnet. That part of it which is neareſt to the magnet, acquires a contrary polarity, and the oppoſite part, the ſame polarity. Thus, if A B, fig. 1, Plate XXV. be an oblong piece of iron, and be brought near the north pole, N, of

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* The decreaſe of this repulſive force, according to the increaſe of the diſtance between the two magnets, is as irregular as the above-mentioned decreaſe of the attractive force.

the magnet N S, then this piece of iron, whilſt ſtanding within the magnet's ſphere of action, will have all the properties of a real magnet; and its end A will be found to be a ſouth pole; viz. contrary to the neareſt pole N of the magnet; whilſt the end B is a north pole. How this is to be made evident will be ſhewn in the ſequel.

The magnetiſm which is acquired by being placed within the influence of a magnet, in ſoft iron, laſts only whilſt the iron continues in that ſituation, and when removed from the vicinity of the magnet, its magnetiſm vaniſhes immediately. But the caſe is quite different with hard iron, and eſpecially with hard ſteel; for the harder the iron or the ſteel is, the more permanent is the magnetiſm which it acquires from the influence of a magnet; but it will be in the ſame proportion more difficult to render it magnetic. If, for inſtance, a ſoft piece of iron and a piece of hard ſteel, both of the ſame ſhape and ſize, be brought within the influence of a magnet at the ſame diſtance, it will be found that the iron is attracted more forcibly, and appears more powerfully magnetic than the ſteel; but if the magnet be removed, the ſoft iron will inſtantly loſe its magnetiſm, whereas the hard ſteel will preſerve it for a long time, having thereby become an artificial magnet.

From thoſe facts three conſequences are evidently deduced, viz. 1ſt, That there is no magnetic attraction but between the contrary poles of magnets; for

for the iron or other ferruginous body, which is preſented to the magnet, muſt itſelf become a magnet before it is attracted; 2dly, It appears why a magnet attracts a piece of ſoft iron more forcibly than hard iron, and much more than hard ſteel; viz. becauſe the latter does not become ſo ſtrongly or ſo eaſily magnetic as the ſoft iron, when preſented to a magnet; and 3dly, that no magnetic repulſion can take place but between poles of the ſame name; for when the north pole, for inſtance, of one magnet does not ſeem to attract or repel, or it actually attracts what was called the north pole of the other magnet; the fact is, either that the two north, or the two ſouth poles have deſtroyed each other; or that the ſuperior force of one of the magnets has actually changed the poles of the weaker magnet; as is, beyond a doubt, proved by experiments.

Neither the magnetic attraction nor the magnetic repulſion is in the leaſt diminiſhed or otherwiſe affected by the interpoſition of any ſort of bodies, except iron, or ſuch bodies as contain iron.

The properties of the magnet are not affected either by the preſence or by the abſence of air.

Heat weakens the power of a magnet, and the ſubſequent refrigeration reſtores it, but not quite to its priſtine degree. A white heat deſtroys it entirely or very nearly ſo; hence it appears, that the powers of magnets muſt be varying continually. Iron in a full red heat or white heat, (as I found by means of very deciſive experiments) is not attracted by the magnet;

magnet; but the attraction begins to act as ſoon as the redneſs begins to diſappear*.

The attractive power of a magnet may be increaſed conſiderably by gradually adding more and more weight to it; keeping it at the ſame time in a proper ſituation, viz. with its north pole towards the north, &c. And on the contrary, that power may be diminiſhed by an improper ſituation, and by keeping too ſmall a piece of iron, or no iron at all, appended to it.

It ſeems that in theſe northern parts of the world, the north pole of a magnet has more power than its ſouth pole, whereas the contrary effect has been ſaid to take place in the ſouthern parts of the world.

Amongſt the natural magnets, the ſmalleſt generally poſſeſs a greater attractive power in proportion to their ſize than thoſe of a larger ſize. I have ſeen a ſmall magnet that weighed about ſix or ſeven grains, and which could lift a weight of about 300 grains. Magnets of above two pounds weight ſeldom lift up ten times their own weight of iron.

It frequently happens, that a natural magnet, cut off from a larger load-ſtone, will be able to lift a greater weight of iron than the original load-ſtone itſelf. This muſt be attributed to the heterogeneous

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* See my Treatiſe on Magnetiſm, 3d edition, Part IV. Chap. IV. for farther particulars relative to it.

nature of the original load-ſtone, of which the part cut off may be the pureſt.

As both magnetic poles together attract a much greater weight than a ſingle pole, and as the two poles of a magnet generally are in oppoſite parts of its ſurface, in which caſe it is almoſt impoſſible to adapt the ſame piece of iron to them both at the ſame time; therefore it has been commonly practiſed to adapt two broad pieces of ſoft iron to the poles of the ſtone, and to let them project on one ſide of the ſtone; for thoſe pieces become themſelves magnetic while thus ſituated, and to them the piece of iron or weight may be eaſily adapted. Thoſe two pieces of iron are generally faſtened upon the ſtone by means of a braſs or ſilver box. The magnet in this caſe is ſaid to be *armed*, and the two pieces of iron are called the *armature*.

Fig. 2, Plate XXV. repreſents an armed magnet, where AB is the load-ſtone, CD, CD, are the armature, or the two pieces of ſoft iron, to the projections of which DD the iron weight F is to be applied. The dots ECDCD repreſent the braſs box with a ring at E, by which the armed magnet may be ſuſpended.

Artificial magnets, when ſtraight, are ſometimes armed in the ſame manner; but they are frequently made in the ſhape of a horſe-ſhoe, having their poles at the truncated extremities, as at N and S, fig. 3, Plate XXV. in which ſhape it is evident, that they want no armature.

It has been ſaid above, that the magnet attracts iron only, or ſuch bodies as contain iron; and as iron is univerſally diſperſed throughout the natural bodies, it is evident that a vaſt number of bodies muſt on that account be attracted by the magnet more or leſs forcibly, in proportion to the quantity and quality of the iron they contain. Indeed it is wonderful to obſerve what a ſmall admixture of iron will render a body ſenſibly attractible by the magnet. Yet it muſt be acknowledged, that though every body which contains iron is in ſome meaſure attracted by the magnet, it does not follow that no other body can be attracted by it. Experience ſhews that a vaſt number of ſubſtances are in a very ſlight degree attractible by the magnet, and thoſe ſubſtances ſeem to contain either no iron at all, or an exceedingly ſmall quantity of it, extremely diffuſed and oxidated. To manifeſt this ſmall degree of attraction, the ſubſtances muſt be placed upon a piece of paper or a light ſhaving of cork, to float upon water, and a ſtrong magnet muſt be gently approached, ſideways, within ſometimes a tenth of an inch diſtance from the ſubſtance under trial. In this manner it will be found that the following ſubſtances are in ſome meaſure affected by the magnet; viz. moſt metallic ores, eſpecially after their having been expoſed to a fire. Zinc, biſmuth, and particularly cobalt, as well as their ores, are almoſt always attracted. Of the earths, the coleareous is the leaſt, if at all, and the ſiliceous is the moſt frequently, attracted.

tracted. The ruby, the chryſolite and the tourmalin are attracted. The emerald, and particularly the garnet, are not only attracted, but frequently acquire a permanent polarity. The opal is weakly attracted. Amber and other combuſtible minerals are attracted, eſpecially after combuſtion. Moſt animal and vegetable ſubſtances after combuſtion are attracted. Even ſoot, and the duſt which uſually falls upon whatever is left expoſed to the atmoſphere, are ſenſibly attracted by the magnet *.

About 15 years ago, I diſcovered ſeveral remarkable facts relative to magnetic attraction; the principal of which are as follows:

If moſt ſpecimens of braſs, which ſhew no attraction towards the magnet, be hammered (viz. be hardened by being beat with a hammer or with a ſtone or otherwiſe) will in that hardened ſtate be attracted. The ſame piece of braſs will no longer be attracted after being ſoftened in the fire; a ſecond hammering will again render it attractible, and ſo on repeatedly.

Moſt of the native grains of platina have the ſame property, viz. hammering renders them attractible by the magnet; and heat deprives them, as well as braſs, of that property.

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* See Brugman De Affinit. Magnet. This author's experiments were publiſhed ſome years ago; and lately the ſame ſlight attraction has been ſhewn under another ſhape, as a new diſcovery. See *La Decade Philoſophique*, N° 21; or the Journals of the Britiſh Royal Inſtitution, N° 8.

The attraction between iron and the magnet, is increaſed by the action of the nitric, and particularly of the ſulphuric acid upon the iron, during the effervеſcence. For this purpoſe the iron was placed in a proper veſſel near one end of a magnetic needle, (viz. a magnetic bar lightly ſuſpended) which was a little deflected from its natural direction by the proximity of the iron; but when diluted ſulphuric acid was poured upon the iron, and the effervеſcence took place, the magnetic needle moved a little towards the iron, ſhewing that the attraction was increaſed by the action of the acid. The nitric acid produced the like effect, but not ſo powerfully. When the effervеſcence was nearly finiſhed, the needle was found to ſtand farther from the iron than it did before the acid was poured upon the iron; which was certainly owing to the iron remaining in an oxygenated ſtate *.

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* For farther particulars reſpecting thoſe diſcoveries, ſee the Philoſophical Tranſactions, vol. 76 and 77, or my Treatiſe on Magnetiſm.

CHAP. II.

OF THE MAGNET'S DIRECTIVE PROPERTY, OR POLARITY.

NO magnet is without a ſouth and a north pole; but it frequently happens that the ſame magnet has more than two poles; viz. two or more north poles, and as many, or at leaſt as many, and one more or leſs, ſouth poles, on different parts of its ſurface; and this principally ariſes from the irregular ſhape of the magnet.

Thoſe various poles are aſcertained by preſenting the various parts of the ſurface of the magnet in queſtion to a given pole (for inſtance, the north) of a ſlender magnet lightly ſuſpended, and obſerving which parts attract it and which repel it; for the latter muſt be north poles, and the former, ſouth poles.

It ſometimes happens, though not frequently, that two poles of the ſame name, and equally powerful, are at the oppoſite extremities of a magnet, and a pole of the other name lies in the middle, in which caſe the magnet has no tendency to place itſelf in the magnetic meridian. But good magnets, of an uniform texture and ſhape, have two poles only,

only, which lie at oppoſite parts of their ſurfaces; ſo that a line drawn from the one to the other, paſſes through the centre of the magnet *. That line is called the *axis*, and a line formed all round the ſurface of the magnet, by a plane which divides the axis into two equal parts, and is perpendicular to it, is called *the equator of the magnet.* Thus philoſophers have appropriated to the magnets, the poles, the equator, as alſo the meridians of the earth ; but, to complete the ſimilarity, magnets have often been made of a ſpherical ſhape, with the poles, the equator, the meridians, &c. marked upon their ſurfaces. When thus ſhaped, they have been called *terrellas*, that is, *ſmall earths*.

When a magnet having two poles is freely ſuſpended, or if it be placed to float upon water and no iron be near, it will place itſelf in the magnetic meridian, viz. with its north pole towards the northern, and of courſe with its ſouth pole towards the ſouthern parts of the world, and that in every part of the world.

This wonderful property of the magnet forms the moſt uſeful part of the ſubject of magnetiſm. It

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* Here it muſt not be underſtood, that the polarity of a magnet reſides only in two points of its ſurface ; for, in truth, it is the half, or a great part of the magnet, that is poſſeſſed of one polarity, (viz. has the property of repelling the like pole of another magnet) and the reſt of the magnet is poſſeſſed of the other polarity ; the poles then are thoſe points in which that power is the ſtrongeſt.

is this property that enables the mariners to conduct their veſſels through vaſt oceans, out of the ſight of land, in any given direction; this directive property guides the miners in their ſubterranean excavations, and the traveller through deſerts otherwiſe impaſſable.

The general method is to keep a magnet, be it artificial or natural, freely ſuſpended, which in that caſe will place itſelf very nearly north and ſouth; then the navigator, by looking at the direction of this magnet, may ſteer his courſe in any required direction. Thus if a veſſel ſetting off from a certain place, muſt go to another place which lies exactly weſtward of the former; the navigator muſt direct it ſo, that its courſe may be always at right angles with the direction of the magnet, keeping the north end of the magnet on the right-hand ſide, and of courſe the ſouth-end on the left-hand ſide of the veſſel; for, as the magnet or magnetic needle lies north and ſouth, the direction eaſt and weſt, which is the intended courſe of the veſſel, is exactly perpendicular to it. A little reflexion will eaſily ſhew how the veſſel muſt be ſteered in any other direction.

An artificial ſteel magnet, fitted for this purpoſe in a proper box, is called the *magnetic needle*, or the *mariner's compaſs*, or *ſea compaſs*, or ſimply the *compaſs* *.

Though

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* It is not preciſely known, when and by whom this wonderful property of the magnet was diſcovered. The moſt

Though the north-pole of the magnet in every part of the world is directed towards the northern parts, and the ſouth pole towards the ſouthern parts; yet that direction ſeldom is exactly in the direction of the poles of the earth. In other words the magnetic meridian, and the real meridian in any given place, ſeldom coincide. The angle which they make is called the *angle of declination*, or *the declination of the magnetic needle*, and this declination is ſaid to be *eaſt* or *weſt*, according as the north pole of the needle is eaſtward or weſtward of the aſtronomical meridian of the place.

This declination is different in different places on land, as well as at ſea; and is, beſides, continually varying in the ſame place. For inſtance, the declination in London is not the ſame as at Paris, or as in India; and the declination in London, or in any other place, at this time, is not the ſame as it was ſome years ago. The change, or the *variation* of the declination may be obſerved even in one or two hours time; or more properly ſpeaking, the magnetic meridian in any one part of the world is con-

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moſt probable accounts ſeem to prove that this directive property of the magnet was known early in the 13th century; and that the perſon who firſt made mariner's compaſſes, at leaſt in Europe, was a Neapolitan of the name of Flavio, or John de Gioja, or Giova, or Gira, who likewiſe lived in the 13th century. See my Treatiſe on Magnetiſm for farther hiſtorical particulars.

tinually ſhifting its ſituation [*]. This is not owing to the various conſtruction of the magnetic needle; for in the ſame place and time all good magnetic needles are directed the ſame way.

The declination and the variation of the declination in different parts of the world is ſo uncertain as not to be foretold; an actual trial is the only method of aſcertaining it. This therefore forms a great impediment to the perfection of navigation. It is true that navigators and other obſervers endeavour to aſcertain the declination in various parts of the world, and ſuch declinations are ſet down upon maps, charts, in books, &c. but on account of the continual variation, they can only ſerve for a few years [†]; nor has it as yet been diſcovered that this

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[*] This variation of the declination was diſcovered by Columbus, in his firſt voyage to America in the year 1492.

[†] The beſt charts of magnetic declination, are a chart by Dr. Halley, which was formed upon the obſervations made in the beginning of the laſt century, and a chart formed by Meſſieurs Mountaine and Dodſon, which contains the obſervations made in the year 1756. In thoſe charts the obſervations are marked by means of dots, and a line is drawn through all the dots, which indicate the ſame declination; but it is continued farther by conjecture or gueſs; thus various lines are drawn indicating the various declinations The line of places, whereupon the magnetic needle points due north and ſouth, is called *the line of no declination.* It is obſervable that thoſe declination lines, though in ſome places very crooked, never croſs each other.

variation or fluctuation is ſubject to any law or period, though various hypotheſes have been offered to the public.

The following Table contains the declination of the magnetic needle at different places upon the earth, as obſerved in the annexed years. N. B. By eaſt or weſt declination it is meant that the north end of the needle inclines eaſtward or weſtward of the aſtronomical meridian.

Latitude North.		Longitude Weſt.		Declination Eaſt.		Years in which the Obſervations were made.
70°	17′	163°	24′	30°	21′	1779.
69	38	164	11	31	0	1778.
66	36	167	55	27	50	
65	43	170	34	27	58	
63	58	165	48	26	25	
59	39	149	8	22	54	
58	14	139	19	24	40	
55	12	135	0	23	29	
53	37	134	53	20	32	
				Weſt.		
50	8	4	40	20	36	1776.
48	44	5	0	22	38	
40	41	11	10	22	27	
33	45	14	50	18	7	
31	8	15	30	17	43	
28	30	17	0	14	0	
23	54	18	20	15	4	
20	30	20	3	14	35	
19	45	20	39	13	11	
16	37	22	50	10	33	
15	25	23	36	9	15	
13	32	23	45	9	25	
12	21	23	54	9	48	

11*

Latitude North.		Longitude Weſt		Declination Weſt.		Years in which the Obſervations were made.
11°	51′	24°	5′	8°	19′	1776. (continued.)
8	55	22	50	8	58	
6	29	20	5	9	44	
4	23	21	2	9	1	
3	45	22	34	8	27	
2	40	24	10	7	42	
1	14	26	2	5	35	
0	51	27	10	4	59	
0	7	27	0	4	27	
South.						
1	13	28	58	3	12	
2	48	29	37	2	52	
3	37	30	14	2	14	
4	22	30	29	2	54	
5	0	31	40	1	26	
6	0	32	50	0	6	
				Eaſt.		
6	45	33	30	00	35	
				Weſt.		
7	50	34	20	00	7	
8	43	34	20	00	15	
				Eaſt.		
9	1	34	50	00	44	
				Weſt.		
10	4	34	49	00	38	
				Eaſt.		
12	40	34	49	1	12	
13	23	34	49	1	1	
14	11	34	49	1	9	
15	33	34	40	1	15	
16	12	35	20	2	4	
18	30	35	50	3	2	
20	8	36	1	5	26	
21	37	36	9	3	24	
24	17	36	8	3	24	
26	47	34	27	3	44	

Latitude North.		Longitude Weſt.		Declination Eaſt.		Years in which the Obſervations were made.
28°	19′	32°	20′	1°	58′	1776.
30	25	26	28	2	37	*(continued.)*
				Weſt.		
33	43	16	30	4	44	
35	37	9	30	5	51	
38	52	23	20	22	12	
		Eaſt.		Eaſt.		
40	36	173	34	13	47	
42	4	167	32	13	17	
				Weſt.		
44	52	155	47	9	28	
46	15	144	50	14	48	
48	41	69	10	27	39	

Declination obſerved in London at different Times.

Years.			
1576	11°	15′	Eaſt Declination.
1580	11	11	
1612	6	10	
1622	6	0	
1633	4	5	
1634	4	5	
1657	0	0	Weſt Declination.
1665	1	22½	
1666	1	35½	
1672	2	30	
1683	4	30	
1692	6	0	
1700	8	0	
1717	10	42	
1724	11	45	
1725	11	56	
1730	13	00	
1735	14	16	
1740	15	40	
1745	16	53	
1750	17	54	
1760	19	12	
1765	20	0	
1770	20	35	
1774	21	3	
1775	21	30	
1780	22	10	
1785	22	50	
1790	23	34	
1795	23	52	
1800	24	7	

From the laſt Table it appears, that when the variation was firſt obſerved, the north pole of the magnetic needle declined eaſtward of the meridian of London; but it has ſince that time been advancing continually towards the weſt; ſo that in the year 1657, the magnetic needle pointed due north and ſouth. At preſent it declines about 24°$\frac{1}{2}$ weſtward, and it ſeems to be ſtill advancing towards the weſt.

It appears likewiſe, that the annual variation is by no means regular, and ſuch is likewiſe the caſe with the daily or hourly variation; which though evidently influenced by heat and cold, does not however follow any known law.

The firſt of the following Tables contains a ſpecimen of hourly variation, as obſerved by the late ingenious Mr. Canton, F. R. S. The ſecond ſhews the mean variation for each month in the year, as deduced from the ſame Mr. Canton's numerous obſervations *.

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* Philoſophical Tranſactions, vol. LI.

The Declination obſerved at different Hours of the ſame Day, viz. June the 27th, 1759.

	Hours.	Minutes	Declin. Weſt		Deg. of Fahren. Therm.
Morning	0	18	19°	2	62
	6	4	18	58	62
	8	30	18	55	65
	9	2	18	54	67
	10	20	18	57	69
	11	40	19	4	68½
Afternoon	0	50	19	9	70
	1	38	19	8	70
	3	10	19	8	68
	7	20	18	59	61
	9	12	19	6	59
	11	40	18	51	57½

The mean Variation for each Month in the Year.

January - -	7'	8"
February - -	8	58
March - -	11	17
April - -	12	26
May - -	13	0
June - -	13	21
July - -	13	14
Auguſt - -	12	19
September - -	11	43
October - -	10	36
November - -	8	9
December - -	6	58

The following are axioms reſpecting the declination of the magnetic needle collected by L. Cotte; to which he adds others reſpecting the northern lights; as being concerned in the movements of the needle.

1. "The greateſt declination of the needle from the north towards the weſt, takes place about two in the afternoon, and the greateſt approximation of it towards the north, about eight in the morning; ſo that from the laſt mentioned hour till about two in the afternoon, it endeavours to remove from the north, and between two in the afternoon and the next morning, to approach it."

2. "The annual progreſs of the magnetic needle is as follows:—Between January and March, it removes from the north; between March and May it approaches it; in June it is ſtationary; in July it removes from it; in Auguſt, September, and October, it approaches it; its declination in October is the ſame as in May; in November and December it removes from the north: its greateſt weſtern declination is at the vernal equinox, and its greateſt approximation to the north, at the autumnal equinox."

3. "The declination of the magnetic needle is different, according to the latitude: among us it has always increaſed ſince 1657; before that period it was eaſterly."

4. "Before volcanic eruptions and earthquakes, the magnetic needle is often ſubject to very extraordinary movements."

5. " The magnetic needle is agitated before and after the appearance of the northern lights: its declination on thoſe occaſions is about noon greater than uſual."

6. " The greater or leſs appearance of theſe northern lights is variable: ſome years this phenomenon is very frequent, in others uncommon; for two or three years they have occurred very ſeldom."

7. " The northern lights are more frequent about the time of the equinoxes than at other periods of the year."

8. " This phenomenon is almoſt conſtant during the long winter in the polar regions, and is the more uncommon the nearer the equator."

9. " Southern lights have been obſerved alſo in the regions near the ſouth pole."

10. " The northern lights are often accompanied with lightning, and a noiſe like that of electricity; while the lightning proceeds partly from the middle of the northern lights, and partly from the neighbouring clouds."

CHAP. III.

OF THE MAGNET'S INCLINATION, OR OF THE DIPPING NEEDLE.

TAKE a globular magnet, or, which is more eaſily procured, an oblong one, like S N, fig. 4, Plate XXV.; the extremity N of which is the north pole, the other extremity S, is the ſouth pole, and A is its middle or equator; place it horizontally upon a table C D; then take another ſmall oblong magnet *n s*, (viz. a bit of ſteel wire, or a ſmall ſewing needle magnetized) and ſuſpend it by means of a fine thread tied to its middle, ſo as to remain in an horizontal poſition, when not diſturbed by the vicinity of iron, or other magnet. Now if the ſame ſmall magnet, being held by the upper part of the thread, be brought juſt over the middle of the large magnet, within two or three inches of it, the former will turn its ſouth pole *s*, towards the north pole, N, of the large magnet; and its north pole *n*, towards the ſouth pole S, of the large one. It will be farther obſerved, that the ſmall magnet, whilſt kept juſt over the middle A of the large one, will remain parallel to it; for ſince the poles of the

ſmall

ſmall magnet are equally diſtant from the contrary poles of the large magnet, they are equally attracted. But if the ſmall magnet be moved a little nearer to one end than to the other of the large magnet, then one of its poles, namely, that which is neareſt to the contrary pole of the large magnet, will be inclined downwards, and of courſe the other pole will be elevated above the horizon. It is evident that this inclination muſt increaſe according as the ſmall magnet is placed nearer to one of the poles of the large one, becauſe the attraction of the neareſt pole will have more power upon it. If the ſmall magnet be brought juſt oppoſite to one of the poles of the large magnet, it will turn the contrary pole towards it, and will place itſelf in the ſame ſtraight line with the axis of the large magnet. N.B. All thoſe ſituations are repreſented in the figure.

After having obſerved this very eaſy experiment, the reader may eaſily comprehend the phenomena of the magnetic inclination, or of the dipping needle upon the ſurface of the earth; for he needs only imagine, that the earth is the large magnet, (as in truth it is) and that any magnet or magnetic needle commonly uſed, is the ſewing needle of the preceding experiment; for admitting that the north pole of the earth is poſſeſſed of a ſouth magnetic polarity, and that the oppoſite pole is poſſeſſed of a north magnetic polarity, it appears, as is confirmed by actual experience, that when a magnet or magnetic

netic needle, properly ſhaped and ſuſpended, is kept near the equator of the earth (or, more properly ſpeaking, near the *magnetic* equator of the earth; ſince neither the magnetic equator, nor the magnetic poles of the earth, coincide with its real equator and poles) it muſt remain in an horizontal ſituation; if it be removed nearer to one of the magnetic poles of the earth, it muſt incline one of its extremities, namely, that which is poſſeſſed of the contrary polarity; and the ſaid inclination muſt increaſe in proportion as the needle recedes from the magnetic equator of the earth. Laſtly, when the needle is brought juſt over one of the magnetic poles of the earth, it muſt ſtand perpendicular to the ground.

A magnetic needle, properly made and ſuſpended for the purpoſe of ſhewing this property, is called the *dipping needle*, and its direction in any place is called the *magnetical line*.

My reader muſt not be ſurprized to hear, that a *ſouth* magnetiſm is attributed to the *north* pole of the earth; it being only meant, that it has a magnetic polarity contrary to that end of the magnetic needle, which is directed towards it; and, as we call the ſame end of the needle a north magnetic pole, we muſt of neceſſity attribute a contrary polarity; viz. a ſouth magnetic polarity to the aſtronomical north pole or northern parts of the earth. It follows that the aſtronomical ſouth pole or ſouthern parts of the earth, muſt be poſſeſſed of north magnetic polarity.

If

If the aſtronomical poles of the earth coincided with its magnetic poles; or even if the magnetic poles ſtood conſtantly at a fixed diſtance from them, the inclination of the needle, as well as its declination would remain unalterable; hence, from obſerving the direction of the magnetic needle in any particular place, the latitude and longitude of that place might be aſcertained; but the caſe is far different; for the magnetic poles of the earth do not coincide with its real poles; they neither are equidiſtant from them; and in fact they are continually ſhifting their places; hence the magnetic needle changes continually and irregularly, not only its horizontal direction, but likewiſe its inclination, according as it is removed from one place to another, as alſo whilſt it remains in the very ſame place. However, the change of dip or of inclination in the ſame place is very trifling. In London about the year 1576, the north pole of the dipping needle ſtood 71° 50″ below the horizon, and in the year 1775 it ſtood at 72° 3′; the whole change of inclination during ſo many years amounting to leſs than a quarter of a degree, allowing the accuracy of the obſervations.

The

The following Table contains a few obſervations on the inclination of the needle in various places.

Latitude North.	Longitude Eaſt.	The North End of the Needle below the Horizon.	Years in which the Obſervations were made
53° 55′	193° 39′	69° 10′	1778.
49 36	233 10	72 29	
	Weſt.		
44 5	8 10	71 34	1776.
38 53	12 1	70 30	
34 57	14 8	66 12	
29 18	16 7	62 17	
24 24	18 11	59 0	
20 47	19 36	56 15	
15 8	23 38	51 0	
12 1	23 35	48 26	
10 0	22 52	44 12	
5 2	20 10	37 25	
South.			
0 3	27 38	30 3	
4 40	30 34	22 15	
7 3	33 21	17 57	
11 25	34 24	9 15	
	Eaſt.	South End below.	
16 45	208 12	29 28	
19 28	204 11	41 0	
21 8	185 0	39 1	1777.
35 55	18 20	45 37	1774.
41 5	174 13	63 49	1777.
45 47	166 18	70 5	1773.

CHAP. IV.

OF COMMUNICATED MAGNETISM.

IT has been already mentioned, that when a ferruginous body comes within a certain diſtance of a magnet, it becomes itſelf a magnet; alſo that this magnetiſm is more eaſily communicated, but at the ſame time more eaſily loſt by ſoft iron than by ſteel. Hence it appears that the beſt method of making artificial magnets, conſiſts in applying one or more powerful magnets to pieces of the hardeſt ſteel, becauſe thoſe pieces will thereby acquire a conſiderable magnetic power, and will retain it for a very long time. In this operation care muſt be had to apply the north pole of the magnet or magnets to that extremity of the piece of ſteel which is required to be made the ſouth pole, and to apply the ſouth pole of the magnet to the oppoſite extremity of the piece of ſteel. In the ſame manner a weak magnet may be rendered more powerful by the application of ſtronger magnets, or its power may be reſtored when loſt.—A magnet, by communicating magnetiſm to other bodies, has its own power rather increaſed than diminiſhed.—There are ſeveral methods of performing this operation; we ſhall deſcribe the beſt preſently; but let us previouſly take notice of what is commonly called the method of magnetizing ſteel without any magnet.

Strictly ſpeaking, this method does not exiſt; for there is no magnetiſm communicated but by the action of another magnet; and in the above-mentioned method the magnetic power is originally communicated from the earth, which is a real magnet, as is evidently and eaſily ſhewn by the following experiment.

Take a ſtraight bar of ſoft iron (one of two or three feet in length, and about three quarters of an inch in diameter, or a common iron kitchen poker, will anſwer perfectly well), and, in theſe northern parts of the world, if you keep it in a vertical poſition, viz. with one end A towards the ground, and with the other end B upwards, you will find that the bar in that ſituation is magnetic; the lower extremity A being a north pole, capable of attracting the ſouth pole of a magnetic needle, and of repelling the north pole of the needle; and the upper extremity B being a ſouth pole.—If you invert the bar, viz. place it with the extremity B downwards, its polarity will be inſtantly reverſed, viz. the extremity B, which is now the loweſt, will be found to be a north pole, and the extremity A a ſouth pole *.

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* An iron bar of four or five feet in length, and above an inch thick, when placed in this ſituation, will be capable of attracting a ſmall bit of iron, or a ſmall common ſewing needle.

The

The explanation of this curious phenomenon is eaſily deduced from the preceding laws; for ſince in theſe northern parts the earth is poſſeſſed of a ſouth polarity, the loweſt part of the iron bar, by being neareſt to it, muſt acquire the contrary, viz. the north polarity; the other extremity of the bar becoming of courſe a ſouth pole. It follows likewiſe (and it is confirmed by actual experiments); 1ſt. That in the ſouthern parts of the earth the loweſt part of the iron bar acquires the ſouth polarity; 2dly, That on the equator the iron bar muſt be kept horizontal, in order that it may acquire magnetiſm from the earth; and 3dly, That even in theſe parts of the earth the moſt advantageous ſituation of the bar is not the perpendicular, but a little inclined to the horizon. In ſhort, in every part of the world the iron bar muſt be placed in the magnetical line; viz. in the direction of the dipping needle.

A bar of hard iron, or of ſteel, will not anſwer for the above deſcribed experiment, the magnetiſm of the earth not being powerful enough to magnetize it.

After this experiment it will be eaſily underſtood that permanent magnetiſm may be communicated in a variety of ways. Thus bars of iron which have ſtood long in a pretty favourable direction, viz. either north and ſouth, or perpendicular, &c. generally acquire a permanent magnetiſm, for the continual action of the earth's magnetiſm daily communicates more and more power to it, at the ſame time that the iron, eſpecially if it be not very ſoft, grows rather harder by ruſting, or working, &c.

If an oblong piece of pretty hard iron be made red hot, and then be left to cool in the magnetical line, it will thereby acquire a degree of permanent magnetiſm.

If an iron bar, whilſt ſtanding in the magnetical line, be ſtruck forcibly and repeatedly with an hammer on one of its ends, it frequently acquires permanent magnetiſm from it. In ſhort, whatever ſeems to render the iron or the ſteel more ſuſceptible of magnetiſm (be it heat, or vibration, or friction), if adminiſtered whilſt the iron or ſteel is in the proper direction, is likely to fix the magnetiſm in it; hence an electric ſhock, or a ſtroke of lightning, or drilling, hammering, &c. frequently magnetizes the tools themſelves, or other pieces of iron and ſteel concerned.

When a magnet is applied with one of its poles to one extremity of a pretty long ſteel bar, the latter will thereby acquire a permanent degree of magnetiſm; but it will be found to have ſeveral poles, viz. the end which has touched the magnet will be found poſſeſſed of the contrary polarity (ſay for inſtance, north); a little farther on, it will be found poſſeſſed of the ſouth polarity; ſome way beyond that you will find another north polarity, and ſo forth alternately. But if the bar be not very long, then it will be found poſſeſſed of two poles only, viz.

a north pole at one end, and a ſouth pole at the other; which ſhews that there is a limit in the length of the bar, which renders it the moſt eligible for an artificial magnet.

A magnet cannot communicate a degree of magnetiſm ſtronger than that which itſelf poſſeſſes; but two or more magnets joined together may communicate a greater power to a piece of ſteel, than either of them poſſeſſes ſingly: hence we have a method of conſtructing very powerful magnets, by firſt conſtructing ſeveral weak magnets, and then joining them together, to form a compound magnet; and to act with great power upon a piece of ſteel.

Since a bar of ſoft iron, ſituated in the magnetical line, is rendered magnetic by the earth; therefore, if in that ſituation we apply a ſmall bit of ſteel, or a common ſewing needle to it, this needle will thereby acquire a permanent degree of magnetiſm, and thus ſeveral needles may be rendered magnetic; then, by joining thoſe needles together in a little bundle, you may with them magnetize ſeveral larger pieces of ſteel, each of which will acquire more power than any of the ſingle needles. With thoſe pieces of ſteel, joined together, you may magnetize bars ſtill larger, and ſo forth.—The needles might alſo be magnetized by means of electric ſhocks, or by hammering; for a ſmart ſtroke of a hammer will frequently render a ſmall needle magnetical. But without inſiſting any longer upon thoſe various methods, I ſhall ſubjoin Mr. Canton's proceſs for conſtructing magnetical bars, the rationale of which will be eaſily deduced by the ingenious reader from the preceding particulars.

According to Mr. Canton *. Let ſix bars be made of ſoft ſteel, about 3 inches long, $\frac{1}{4}$ inch broad, and $\frac{1}{20}$ inch thick. Let alſo ſix other ſteel bars be made quite hard, and about ſix inches long, half an inch broad, and one eighth thick. Each of thoſe ſets of bars muſt have two pieces of ſoft iron called *ſupports* or *conductors*, both equal to one bar of the reſpective ſet. One end of each of theſe 12 bars muſt be marked with a line, which end is to become the north pole. Have ready alſo an iron poker and tongs that have been long in uſe.

Place the poker nearly upright, or rather in the magnetical line, with its point downwards; and let one of the ſoft ſteel bars be tied, by means of a thread, to the middle of it, and with the marked end downwards; then with the lower end of the tongs held alſo in an upright poſition, or in the magnetical line, ſtroke the ſteel bar from the marked end upwards, about 10 times, on both ſides, which will give it power enough to keep ſuſpended a ſmall key. Thus communicate the magnetiſm to four of the ſmall bars.

This done, lay the two other ſmall bars on a table parallel to each other, about a quarter of an inch

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† Phil. Tranſ. for the years 1751 and 1752.

asunder,

aſunder, and between their iron conductors A B, C D, fig. 5, Plate XXV. taking care to place the marked end of one of the bars on one ſide, and the marked end of the other bar on the oppoſite ſide. Now place the four bars, already made magnetic, in the form ſhewn in fig. 6, Plate XXV. viz. two with their north poles downwards, and the other two with their ſouth poles downwards. The two of each pair muſt be placed breadth to breadth, and the two pairs being put contiguous to each other at top, muſt be kept open at a ſmall angle by the interpoſition of ſome hard ſubſtance I. This ſort of compound magnet, formed of the four bars, muſt be placed with its aperture on the middle of one of the ſoft bars A C, taking care to let the ſouth poles H be towards the marked end of the bar A C, and the north poles F towards the other extremity. In this poſition, the compound magnet muſt be ſlid from end to end of the ſaid bar, viz. when the poles H are arrived at C, move the compound magnet backwards the other way, till the poles F come to A, &c. Thus ſtroke the lying bar four times, ending at the middle; from whence take up the compound magnet, and remove it to the middle of the other lying bar BD, taking care, as above, to let the ſouth poles be towards the marked end of the bar; rub this in the like manner; then turn the bars A C, B D, with the ſides that ſtood towards the table, upwards, and repeat the operation on thoſe other ſides. This being done, take

take up the two bars A C, B D, and let them form the inner two of the compound magnet; and place thoſe which were before the two outſide ones, between the pieces of iron or conductors, and rub them with the compound magnet formed out of the other four bars, in the ſame manner as before. This operation muſt be repeated till each of the ſix bars has been rubbed four or five times, by which means they will acquire a conſiderable degree of magnetic power.

When the ſmall bars have been thus rendered magnetic, in order to communicate the magnetiſm to the large bars, lay two of them upon the table, between their two conductors, or pieces of iron, in the ſame manner, and with the ſame precautions, as were uſed for the ſmall bars; then form a compound magnet with the ſix ſmall bars, placing three of them with the north poles downwards, and the three others with their ſouth poles downwards. Place thoſe two parcels at an angle, as was done with four of them, the north extremity of one parcel being put contiguous to the ſouth extremity of the other; and with this compound magnet, ſtroke four of the large bars, one after the other, about 20 times on each ſide, by which means they will acquire ſome magnetic power.

When the four large bars have been ſo far rendered magnetic, the ſmall bars are laid aſide, and the large ones are ſtrengthened by themſelves, in the ſame manner as was done with the ſmall bars.

With ſome ſort of ſteel, a few ſtrokes are ſufficient to impart to them all the power they are capable of retaining; other ſorts require a longer operation; and ſometimes it is impoſſible to give them more than a juſt ſenſible degree of magnetiſm.

In order to expedite the operation, the bars ought to be fixed in a groove, or between braſs pins; otherwiſe the attraction and friction between the bars will be continually deranging them, when placed between the conductors.

A ſet of ſuch bars are exceedingly uſeful for magnetizing other bars, or needles of compaſſes, &c. their power may alſo be increaſed when loſt or impaired by miſmanagement, &c. A ſet of ſuch bars, viz. ſix bars and the two iron conductors, may be preſerved in a box; taking care to place the north pole of one contiguous to the ſouth pole of the next, and that contiguous to the north pole of the third, &c. as ſhewn in fig. 7, Plate XXV *.

After what has been ſaid above, I need not deſcribe how a knife, or any piece of ſteel, &c. may be rendered magnetic, or in what manner a weak magnet may be rendered more powerful. But it may perhaps be neceſſary to ſay ſomething concerning the communication of magnetiſm to crooked bars like ABC, fig. 8, Plate XXV.

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* For other methods of magnetizing, ſee my Treatiſe on Magnetiſm.

Place

Place the crooked bar flat upon a table, and to its extremities apply the magnetic bar D F, E G; joining their extremities F, G, with the conductor or piece of ſoft iron F G: then to its middle apply the magnetic bars placed at an angle, as in Mr. Canton's method, or you may uſe two bars only, placed as ſhewn in fig. 8, and ſtroke the crooked bar with them from end to end, following the direction of that bent bar; ſo that on one ſide of it the magnetic bars may ſtand in the direction of the dotted repreſentation L K. In this manner, when the piece of ſteel ABC has been rubbed a ſufficient number of times on one ſide, it muſt be turned with the other ſide upwards, &c.

In this proceſs (as well as has been directed in Mr. Canton's) the magnets D F, E G, as alſo the magnets H, I, muſt be placed ſo that their ſouth poles be towards that extremity of the crooked ſteel, which is required to be made the north pole, &c.

CHAP. V.

THEORY OF MAGNETISM.

IN the preſent chapter we ſhall briefly take notice, 1ſt, Of the principal phenomena of the earth's magnetiſm; and 2dly, Of the ſuppoſed magnetic fluid.

That the earth acts as a great magnet is ſo clearly indicated by a variety of facts and conſiderations, that at preſent it is hardly poſſible to doubt of it. In the firſt place the directive property of the magnetic needle on the ſurface of the earth is ſo analogous to that of a ſmall needle upon the ſurface of a common magnet or terrella, as to ſtrike every obſerver; 2dly, The magnetiſm which iron acquires by its poſition, is another ſtriking indication of the earth's magnetiſm; and 3dly, The vaſt maſſes of iron, in various ſtates, which are to be found almoſt every where in the bowels of the earth, and which are frequently magnetic, prove beyond a doubt that the earth is a vaſt but irregular magnet, and that its magnetiſm ariſes from the magnetiſm of all the ferruginous bodies that are contained in it; ſo that the magnetic poles of the earth muſt be conſidered as the centres or collected powers of all thoſe magnetic ferruginous ſubſtances. It follows likewiſe that according as thoſe maſſes of iron are affected by heat and cold, by decompoſition, by mixture with other ſubſtances, by volcanos, by earthquakes, or mechanical derangements, &c. ſo the magnetic poles of the earth muſt ſhift their ſituation; and this is the cauſe of the variation of the magnetic needle*.

The above-mentioned cauſes are ſufficient to account for the daily, or hourly, or yearly variations, though it is not and perhaps it will never be in our power to determine what part of the effect is due to each of thoſe cauſes, or what is the preciſe reſult of the whole. It is therefore needleſs to ſuppoſe, according to ſome philoſophers, that a large moveable magnet is contained within the earth, or to admit other hypotheſes ſtill leſs probable.

The great deſideratum in magnetics, is to know the cauſe, which, in a magnet, of whatever ſort it be, produces the attraction, repulſion, &c. it being wonderful to obſerve that, by the mere contact, or even by being brought within a certain diſtance of a magnet, a piece of ſteel, &c. acquires ſeveral remarkable properties, which it afterwards retains

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* See the late Dr. Lorimer's attempt to explain the cauſe of the variation of the Magnetic Needle in my Treatiſe on Magnetiſm, 3d Edition; alſo page 254.

with

with great obſtinacy, and that without having its weight, ſhape, colour, or hardneſs, altered in and ſenſible degree.

Human ingenuity has contrived abundance of hypocheſes in explanation of thoſe phenomena; but the inſufficiency of moſt of them renders it uſeleſs to ſtate them in this work, excepting however one which was propoſed by Mr. Aepinus, and which is ſimilar to the Franklinian Theory of Electricity*.

The attentive reader muſt undoubtedly have remarked ſeveral ſtrong points of analogy between magnetiſm and electricity; ſuch as the analogy between the two poles of a magnet and the two electricities; the attraction which takes place between magnetic poles of different denominations analogous to the attraction between bodies differently electrified, &c. Now Mr. Aepinus is led to imagine, that there exiſts a fluid productive of all the magnetic phenomena, and conſequently to be called *the magnetic fluid*; that this fluid is ſo very ſubtile as to penetrate the pores of all bodies; and that it is of an elaſtic nature, viz. that its particles are repulſive of each other.

He farther ſuppoſes, that there is a mutual attraction between the magnetic fluid and iron, or

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* Aepini Tentamen Theoriæ Electricis et Magnetiſmi, chap. I. ſect. III.

other

other ferruginous bodies; but that no other ſubſtance has any action upon this fluid. He then obſerves, that there is a great deal of reſemblance between ferruginous bodies and electrics, or non-conductors of electricity; for the magnetic fluid paſſes with difficulty through the pores of the former, as well as the electric fluid paſſes with difficulty through the pores of the latter. However, there is not a body which has any action on the magnetic fluid, and is, at the ſame time, analogous to non-electrics; for inſtance, there is not a body which attracts the magnetic fluid, and which is, at the ſame time, permeable by that fluid. In iron, indeed, a kind of gradation of this ſort ſeems to exiſt; for the ſofter the iron is, the more freely does the magnetic fluid pervade its pores, and *vice verſa*.

According to this hypotheſis, iron, and all ferruginous ſubſtances, contain a quantity of magnetic fluid, which is equably diſperſed through their ſubſtance, when thoſe bodies are not magnetic; in which ſtate they ſhew no attraction or repulſion, becauſe the repulſion between the particles of the magnetic fluid is balanced by the attraction between the matter of thoſe bodies and the ſaid fluid, in which caſe thoſe bodies are ſaid to be in a natural ſtate. But when in a ferruginous body, the quantity of magnetic fluid belonging to it, is driven to one end, then the body becomes magnetic, one extremity of it being now overcharged with magnetic fluid, and the other extremity undercharged. Bodies thus conſtituted, viz. rendered magnetic, exert a repulſion between their overcharged extremities, in virtue of the repulſion between the particles of that exceſs of magnetic fluid, which is more than ſufficient to balance, or to ſaturate, the attraction of their matter. There is an attraction exerted between the overcharged extremity of one magnetic body, and the undercharged extremity of the other, on account of the attraction between the magnetic fluid and the matter of the body; but, to explain the repulſion which takes place between their undercharged extremities, we muſt either imagine that the particles of ferruginous bodies, when deprived of the magnetic fluid, muſt be repulſive of each other, or that the undercharged extremities *appear* to repel each other, only becauſe either of them attracts the oppoſite overcharged extremity; both which ſuppoſitions are embarraſſed with difficulties.

A ferruginous body, according to this hypotheſis, is rendered magnetic by having the equable diffuſion of the magnetic fluid diſturbed throughout its ſubſtance; ſo as to have an overplus of it in one or more parts, and a deficiency of it in one or more other parts: and it remains magnetic as long as its impermeability prevents the reſtoration of the equable diffuſion

diffuſion of fluid, or of the balance between the overcharged and the undercharged parts. Moreover, the piece of iron is rendered magnetic by the action of a magnet, becauſe, when the overcharged part or pole of the magnet is preſented to it, the overplus of magnetic fluid in that pole repels the magnetic fluid away from the neareſt extremity of the iron, (which therefore becomes undercharged) to a more remote part of the iron which becomes overcharged. If the iron be magnetized by the contact of the undercharged ſide of the magnet, then the matter of the latter attracts the magnetic fluid of the iron to that extremity of the iron which lies neareſt to itſelf.

In a ſimilar manner you may explain the action of two magnets upon each other.

I ſhall conclude this chapter by obſerving, that the magnet has not been found to have any action whatever upon the human body, and of courſe the idle ſtories of its being beneficial to perſons afflicted with the tooth-ach, or with white ſwellings, or to parturient women; as alſo of the wounds inflicted with a magnetized knife being mortal, more than if the knife had not been magnetic, have not the leaſt foundation in truth or experience. The bare-faced impoſition which has for ſeveral years been practiſed under the name of *animal magnetiſm*, is another abſurdity.

In the *Reichſanzeiger*, a German periodical publication, N° CCXXII. for 1797, it is ſaid, that a certain

certain perſon having an artificial magnet ſuſpended from the wall of his ſtudy, with a piece of iron adhering to it, remarked, for ſeveral years, that the flies in the room, though they frequently placed themſelves on other iron articles, never ſettled upon the artificial magnet.

CHAP. VI.

THE CONSTRUCTION AND THE USE OF THE PRINCIPAL MAGNETICAL INSTRUMENTS, AS ALSO THE DESCRIPTION OF EXPERIMENTS USEFUL FOR THE ILLUSTRATION OF THE SUBJECT.

THE magnetical inſtruments may be reduced to three principal heads; viz. 1ſt, the magnets or magnetic bars, which are neceſſary to magnetize needles of compaſſes, or ſuch pieces of ſteel, iron, &c. as may be neceſſary for diverſe experiments; and which have already been ſufficiently explained in the preceding pages; 2dly, the compaſſes, ſuch as are uſed in navigation, and for other purpoſes, which are only magnetic needles nimbly ſuſpended in boxes, and which, according to the purpoſes for which they are particularly employed, have ſeveral appendages, or differ in ſize, and in accuracy of diviſions, &c. whence they derive the different names of pocket compaſſes, ſteering compaſſes, variation compaſſes, and azimuth compaſſes; and 3dly, the dipping needle *.

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* A curious contrivance, which is at once a dipping and a variation needle, was ſome years ago made by the late Dr. Lorimer. See a deſcription of it in the Phil. Tranſ. vol. 65, or in my Treatiſe on Magnetiſm.

The magnetic needles, which are commonly uſed at ſea, are between four and ſix inches long; but thoſe which are uſed for obſerving the daily variation, are made a little longer, and their extremities point the variation upon an arch or circle properly divided and affixed to the box*.

The beſt ſhape of a magnetic needle is repreſented in fig. 9 and 10, Plate XXV.; the firſt of which ſhews the upper ſide, and the ſecond ſhews a lateral view of the needle, which is of ſteel, having a pretty large hole in the middle, to which a conical piece of agate is adapted by means of a braſs piece O, into which the *agate cap* (as is called) is faſtened. Then the apex of this hollow cap reſts upon the point of a pin F, which is fixed in the centre of the box, and upon which the needle, being properly balanced, turns very nimbly †. For common purpoſes, thoſe needles have a conical perforation made in the ſteel itſelf, or in a piece of braſs which is faſtened in the middle of the needle ‡.

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* See the deſcription of my new variation compaſs in my Treatiſe on Magnetiſm, the 2d or 3d edition.

† It muſt be obſerved, that the needle which is balanced before it is magnetized, will loſe its balance, by being magnetized on account of the dipping, as ſhewn in the third chapter; therefore a ſmall weight or moveable piece of braſs is placed on one ſide of the needle, as ſhewn in fig. 10, by the ſhifting of which, either nearer to or farther from the centre, the needle may always be balanced.

‡ The ſimpleſt magnetic needles are made of common ſewing needles magnetized, and laid to ſwim upon water.

A mariner's compaſs, or compaſs generally uſed on board of ſhips, is repreſented in Plate XXV. fig. 11. The box, which contains the card or fly with the needle, is made of a circular form, and either of wood, or braſs, or copper. It is ſuſpended within a ſquare wooden box, by means of two concentric circles, called *gimbalds*, ſo fixed by croſs axes *a*, *a*, *a*, *a*, to the two boxes, (ſee the plan, fig. 12, Plate XXV.) that the inner one, or compaſs box, ſhall retain an horizontal poſition in all motions of the ſhip, whilſt the outer or ſquare box is fixed with reſpect to the ſhip. The compaſs box is covered with a pane of glaſs, in order that the motion of the card may not be diſturbed by the wind. What is called the card, is a circular piece of paper, which is faſtened upon the needle, and moves with it. Sometimes there is a ſlender rim of braſs, which is faſtened to the extremities of the needle, and ſerves to keep the card ſtretched. The outer edge of this card is divided into 360 equal parts or degrees, and within the circle of thoſe diviſions it is again divided into 32 equal parts, or arcs, which are called the *points of the compaſs*, or *rhumbs*, each of which is often ſubdivided into quarters. The initial letters N, N E, &c. are annexed to thoſe rhumbs, to denote the North, North Eaſt, &c. The middlemoſt part of the card is generally painted with a ſort of ſtar, whoſe rays terminate in the above-mentioned diviſions. To avoid confuſion on thoſe letters, &c. are not drawn in the figure.

The azimuth compaſs is nothing more than the above-

above-mentioned compaſs, to which two ſights are adapted, through which the ſun is to be ſeen, in order to find its azimuth, and from thence to aſcertain the declination of the magnetic needle at the place of obſervation; ſee fig. 13, Plate XXV. The particulars in which it differs from the uſual compaſs, are the ſights F, G; in one of which, G, there is an oblong aperture with a perpendicular thread or wire ſtretched through its middle; and in the other ſight F, there is a narrow perpendicular ſlit. The thread or wire H I is ſtretched from one edge of the box to the oppoſite. The ring A B of the gimbalds reſts with its pivots on the ſemicircle C D, the foot E of which turns in a ſocket, ſo that whilſt the box K L M is kept ſteady, the compaſs may be turned round, in order to place the ſights F, G, in the direction of the ſun*.

There are, on the inſide of the box, two lines drawn perpendicularly along the ſides of the box, juſt from the points where the thread H I touches the edge of the box. Theſe lines ſerve to ſhew how many degrees the north or ſouth pole of the needle is diſtant from the azimuth of the ſun; for which purpoſe, the middle of the apertures of the ſights F, G, the thread H I, and the ſaid lines,

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* The pivots of the gimbalds of this, as well as of the common ſort of compaſſes, ſhould lie in the ſame plane with the point of ſuſpenſion of the needle, in order to avoid as much as poſſible the irregularity of the vibrations.

muſt be exactly in the ſame vertical plane. The uſe of the thread HI, which is often omitted in inſtruments of this ſort, is likewiſe to ſhew the degrees between the magnetic meridian and the azimuth, when the eye of the obſerver ſtands perpendicularly over it. On the ſide of the box of this ſort of compaſſes, there generally is a nut or ſtop, which, when puſhed in, bears againſt the card and ſtops it, in order that the diviſions of the card which coincide with the lines in the box, may be more commodiouſly read off*.

The dipping needle, though of late much improved, is however ſtill far from perfection. The general mode of conſtructing it is to paſs an axis quite through the needle, to let the extremities of this axis, like thoſe of the beam of a balance, reſt upon its ſupports, ſo that the needle may move itſelf vertically round, and when ſituated in the magnetic meridian, it may place itſelf in the magnetic line. The degrees of inclination are ſhewn upon a divided circle, in the centre of which the needle is ſuſpended. Fig. 14, Plate XXV. repreſents a dipping needle of the ſimpleſt conſtruction; A B is the needle, the axis of which F E reſts upon the middle of two lateral bars C D, C D, which are made faſt to the frame that contains the divided

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* What the azimuth of a celeſtial object is, and how it may be aſcertained, will be ſhewn in the next volume of this work.

circle AIBK. This machine is fixed on a ſtand G; but, when uſed at ſea, it is ſuſpended by a ring H, ſo as to hang perpendicularly. When the inſtrument is furniſhed with a ſtand, a ſpirit level O is generally annexed to it, and the ſtand has three ſcrews, by which the inſtrument is ſituated ſo that the centre of motion of the needle, and the diviſion of 90° on the lower part of the divided circle, may be exactly in the ſame line, perpendicular to the horizon.

The greateſt imperfections of this inſtrument is the balancing of the needle, and the difficulty of aſcertaining whether the needle retains its equipoiſe. In making the obſervation of the dip at any particular place, the beſt method to avoid the error ariſing from the want of balance, is, firſt to obſerve the dip of the needle, then to reverſe its magnetiſm, by the application of magnetic bars, ſo that the end of the needle, which before was elevated above the horizon, may now be below it; and laſtly, to obſerve its dip again; for a mean of the two obſervations will be pretty near the truth, though the needle may not be perfectly balanced.

The few experiments which follow, are principally intended to illuſtrate the theory. As for entertaining magnetical experiments, the ingenious reader may eaſily derive them from the general ſubject which has been already explained.

1. The method of diſcovering whether a body is attractible by the magnet or not, and whether it has any

any polarity or not, or which is its ſouth, and which its north pole, is ſo eaſily performed as not to require many words; for by approaching a magnet to the body in queſtion (which, if neceſſary, may be ſet to ſwim upon water), or by preſenting the body in queſtion to either extremity of a ſuſpended magnetic needle, the deſired object may be obtained.

2. Tie two pieces of ſoft iron wire, A B, A B, fig. 15 and 16, Plate XXV. each to a ſeparate thread, A C, A C, which join at top, and forming them into a loop, ſuſpend them ſo as to hang freely. Then bring the marked end D, which is the north, of a magnetic bar, juſt under them, and the wires will immediately repel each other, as ſhewn in fig. 16; and this divergency will increaſe to a certain limit, according as the magnet is brought nearer, and *vice verſa.* The reaſon of this phenomenon is that by the action of the north magnetic pole D, both the extremities B, B, of the wires, acquire the ſame, viz. the ſouth polarity; conſequently they repel each other; and the extremities A, A, acquire the north polarity, in conſequence of which they alſo repel each other.

If inſtead of the north pole D, you preſent the ſouth pole of the magnetic bar, the repulſion will take place as before; but now the extremities B, B, acquire the north, and the extremities A, A, acquire the ſouth, polarity.

On removing the magnet, the wires, if of ſoft iron, will ſoon collapſe, having loſt all their magnetic power; but if ſteel wires, or common ſewing needles be uſed, they will continue to repel each other after the removal of the magnet; the magnetic power being retained by ſteel.

3. Lay a ſheet of paper flat upon a table, ſtrew ſome iron filings upon the paper, place a ſmall magnet among them; then give a few gentle knocks to the table, ſo as to ſhake the filings, and you will find that they diſpoſe themſelves about the magnet NS, as ſhewn in fig. 17, Plate XXV. the particles of iron clinging to one another, and forming themſelves into lines, which at the very poles N, S, are in the ſame direction with the axis of the magnet; a little ſideway of the poles they begin to bend, and then they form complete arches, reaching from ſome point in the northern half of the magnet, to ſome other point in the ſouthern half. The reaſon of this phenomenon is not, as ſome perſons imagine, that a current of fluid iſſues from one pole and enters at the other pole of the magnet; for if that were the caſe, the iron filings would be all driven upon one of the poles. But the true reaſon is, that each of the particles of iron is become actually magnetic, and poſſeſſed of the two poles, in conſequence of which each particle, at the place where it happens to ſtand, diſpoſes itſelf in the ſame manner as any other magnet would do; and moreover attracts with its extremities the contrary poles of other particles.

4. Take a ſtrong magnet, and find out by trial ſuch

ſuch a piece of iron as is very little heavier than what the magnet will ſupport. It is plain, that if you affix this iron to one pole of the magnet, the moment you remove your hand the iron will drop off; but if, before you remove your hand, you preſent another larger piece of iron to the under part of the former, and at about half an inch from it, you will then find that the magnet will be able to ſupport the firſt piece of iron which it could not ſupport before, when the ſecondary piece of iron ſtood not below it. In ſhort, a magnet can lift a greater weight of iron from over another piece of iron, ſuch as an anvil or the like, than from a table; the reaſon of which is, that in the former caſe, the iron baſis or inferior piece of iron, becoming itſelf in ſome meaſure magnetic, helps to increaſe the magnetiſm of the firſt piece of iron, and conſequently tends to increaſe the attraction.

5. Place a magnetic bar A B, fig. 18, Plate XXV. ſo that one of its poles may project a ſhort way beyond the table, and apply an iron weight C to it; then take another magnetic bar, D E, like the former, and bring it parallel to and juſt over the other, at a little diſtance, and with the contrary poles towards each other; in conſequence of which the attraction of B will be diminiſhed, and the iron C, if ſufficiently heavy, will drop off, the magnet AB being then only able to ſupport a ſmaller piece of iron. By bringing the magnets ſtill nearer to each other, the attraction of B will be diminiſhed ſtill farther; and,

and, when the two magnets come quite into contact, (provided they are equal in power) the attraction between B and C will vaniſh entirely; but if the experiment be repeated with this difference, viz. that the homologous poles of the magnets be brought towards each other, then the attraction between B and C, inſtead of being diminiſhed, will be increaſed.

6. Let an iron wire of about a quarter of an inch in diameter, and 4 or 5 inches long, be bent ſomewhat like a Gothic arch, viz. with a ſharp corner in the middle, as ABC, fig. 19, Plate XXV. and tie it faſt to any proper ſtand, or let an aſſiſtant hold it, with the corner downwards; then apply either pole of the magnet DE to one of its extremities A, and whilſt the magnet remains in that ſituation, apply a piece of iron H, of no great ſize, to the corner C, and you will find that the iron remains ſuſpended. Now, if another magnet be applied to the other extremity B of the crooked iron, ſo that the pole G may be contrary to the pole E, the iron H will immediately drop off; but if the pole G be analogous to the pole E, viz. be both ſouth or both north, then the iron H not only will remain adhering to C, but the ſaid corner will be capable of ſupporting a weight ſtill greater than H. The reaſon of which is, that in the former caſe the extremities A and B, of the bent iron, being poſſeſſed of different polarities, the corner C became the magnetic centre, where there is no attraction nor repulſion; whereas in

in the ſecond caſe, both extremities of the bent iron being poſſeſſed of the ſame polarity, the corner C acquired the contrary polarity. In this latter caſe the crooked iron muſt have two magnetic centres, viz. one on each ſide.

7. In order to imitate in ſome meaſure, natural magnets, take martial æthiops, or, which is more eaſily procured, reduce into very fine powder the ſcales of iron which fall off from the red-hot iron when ſhammered in blackſmiths ſhops: mix this powder with drying linſeed oil, ſo as to form it into a very ſtiff paſte, and ſhape it in a proper mould, into the form of a terrella or human head, &c. This done, place it in a warm place during ſome weeks, by which means it will become very hard; then render it magnetic by the application of powerful magnets, and it will acquire a conſiderable permanent power.

THE END OF VOLUME THE THIRD.

Plate XVIII.

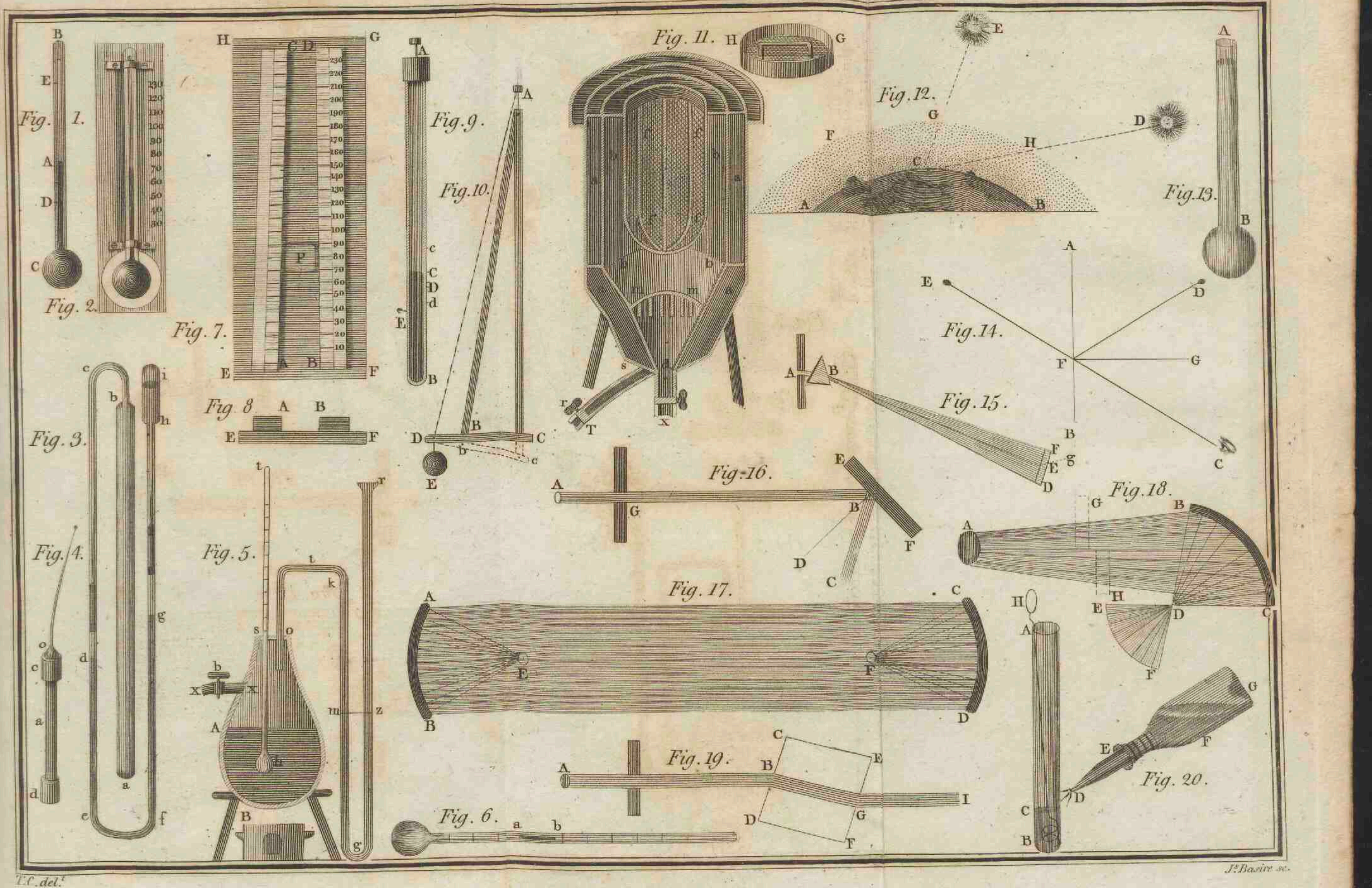

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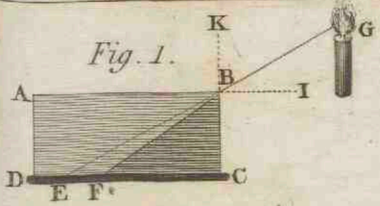
Fig. 1.



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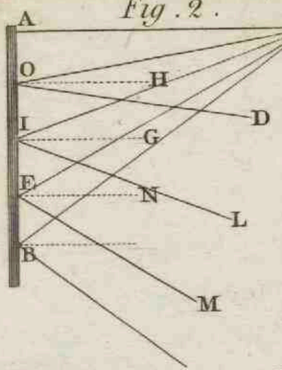

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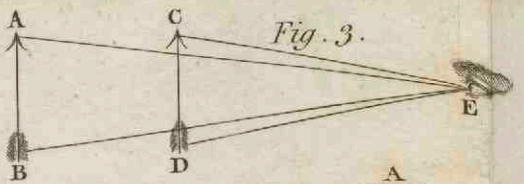

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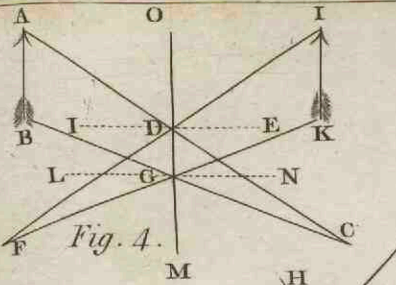

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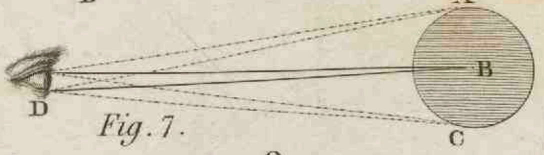

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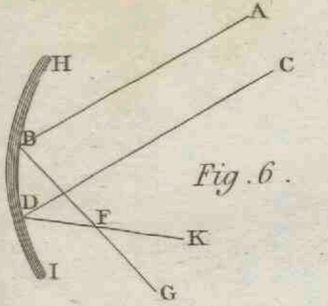

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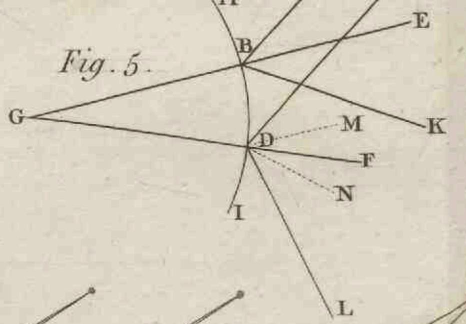

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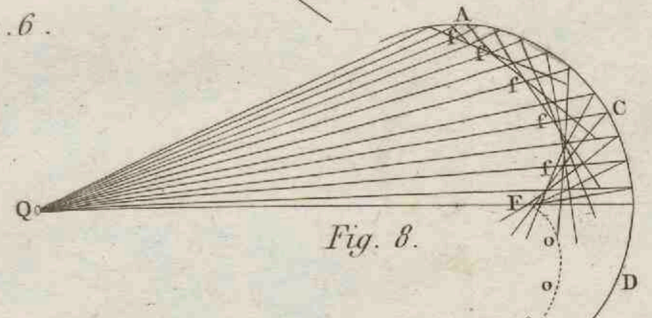

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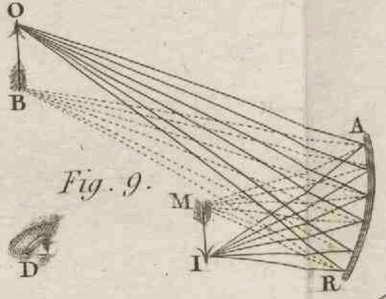

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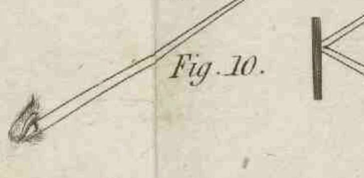

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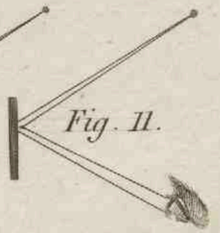

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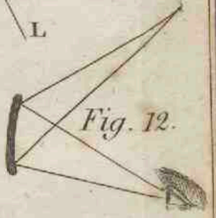

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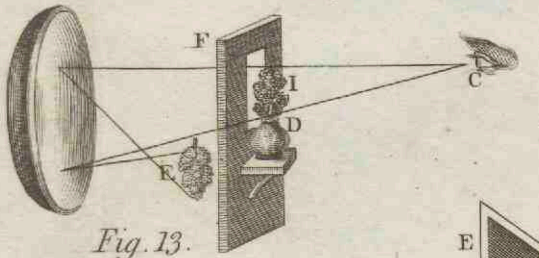

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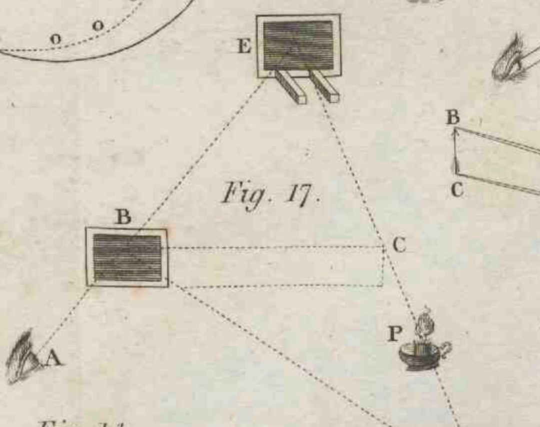

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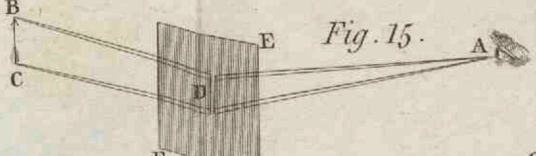

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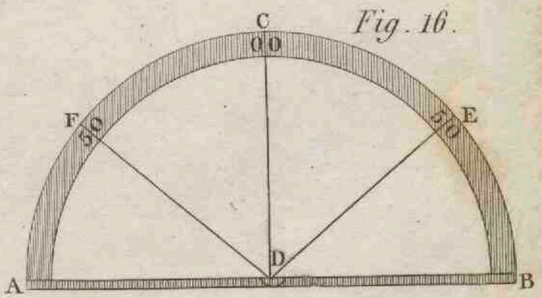

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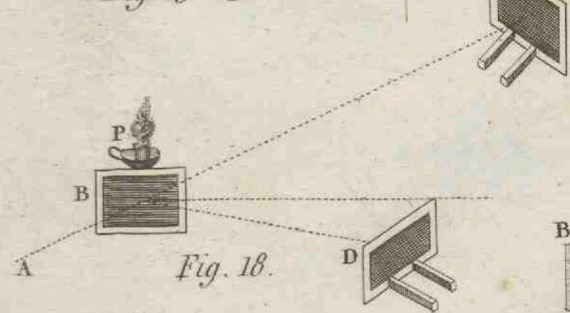

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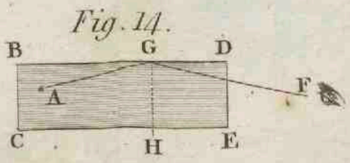

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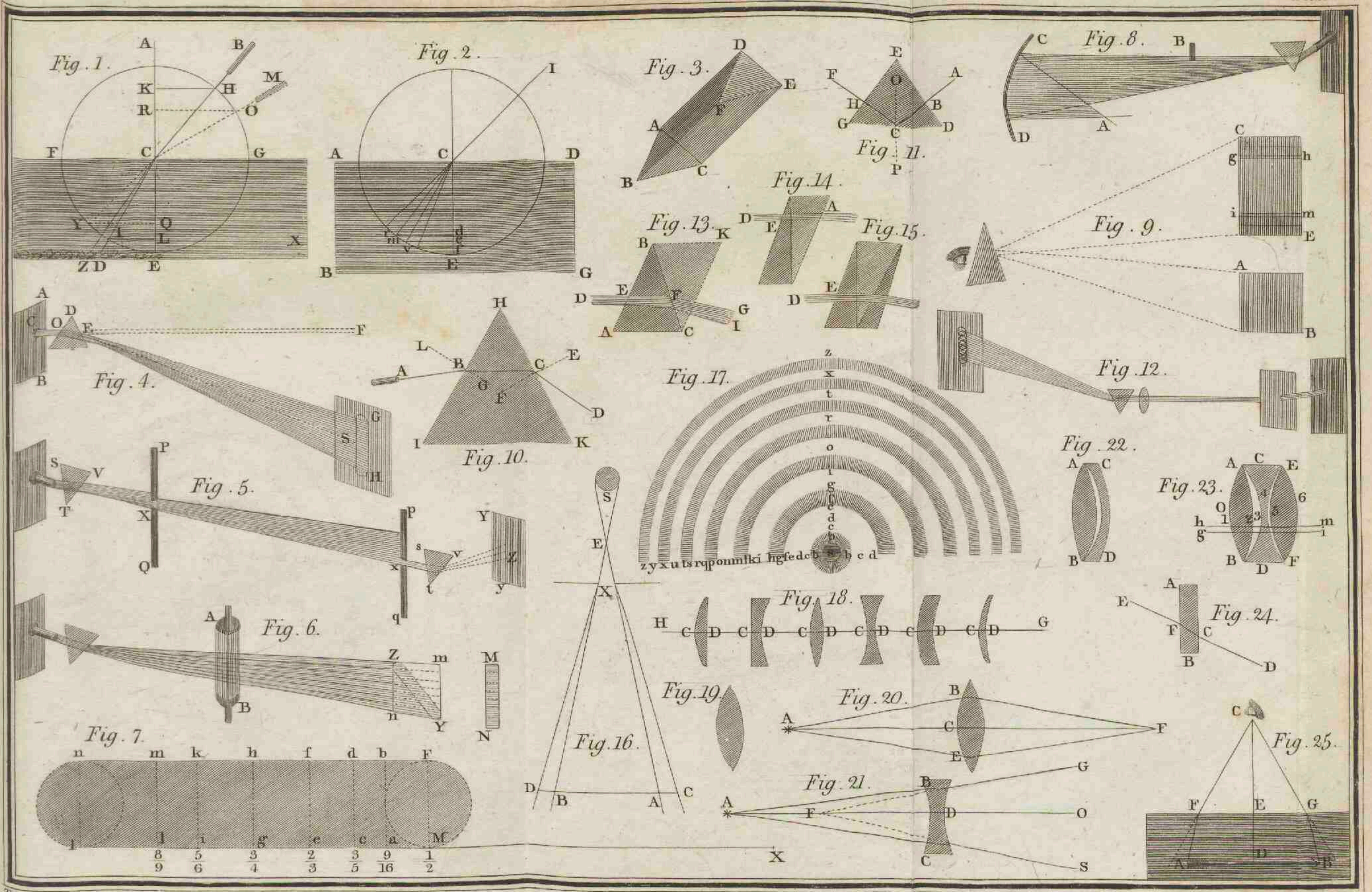

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Plate XXI.

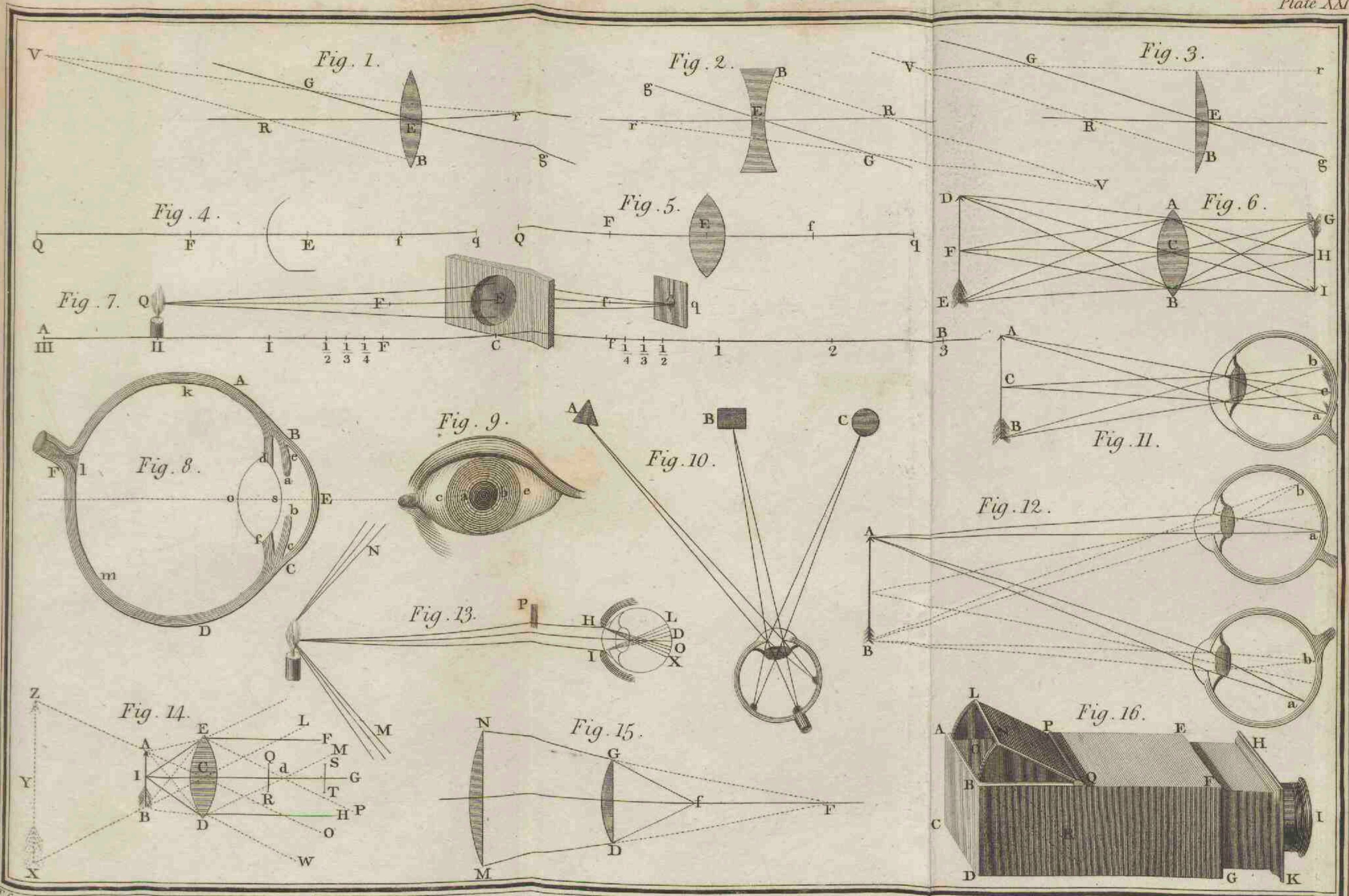

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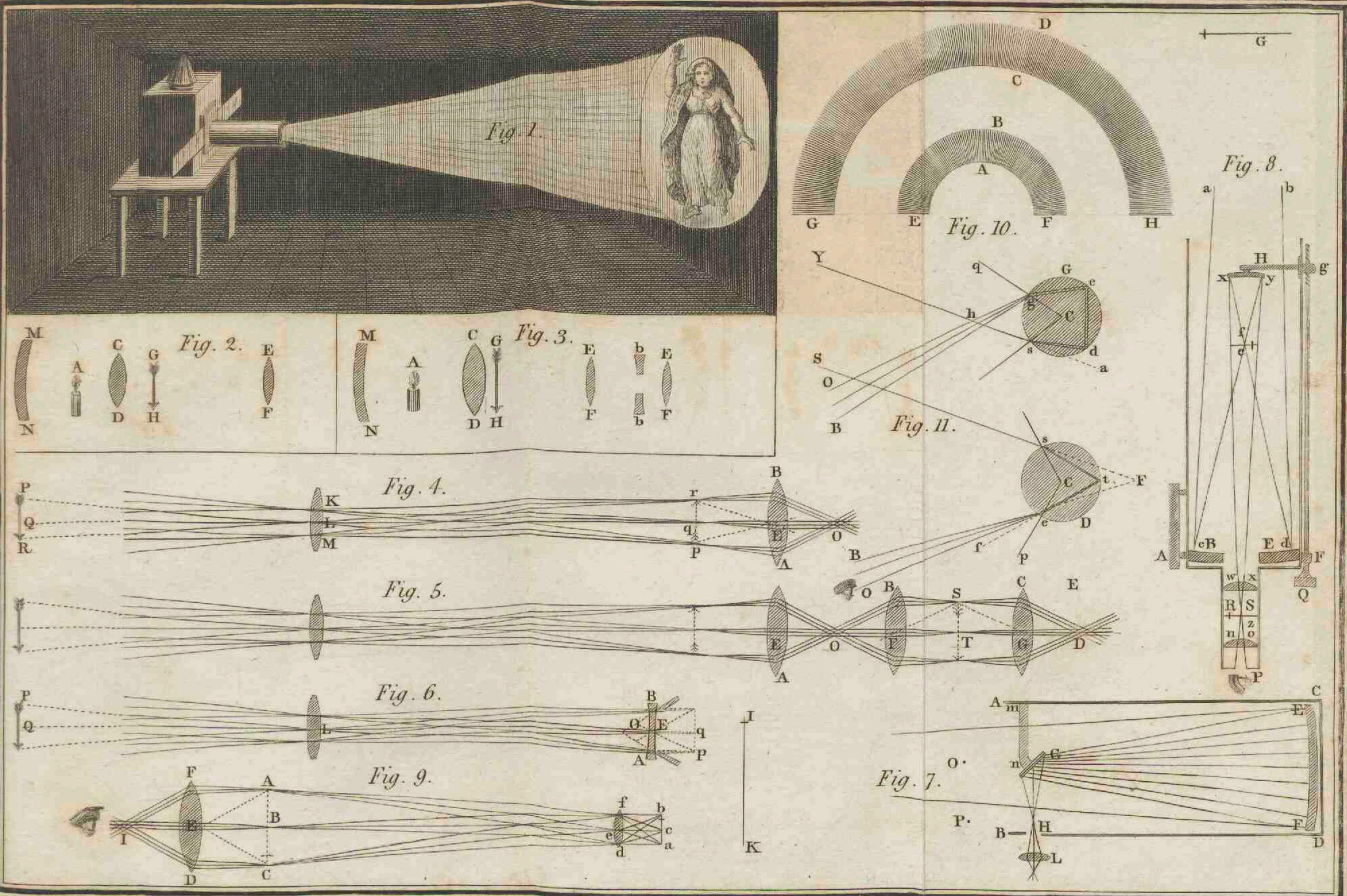
Plate XXII.



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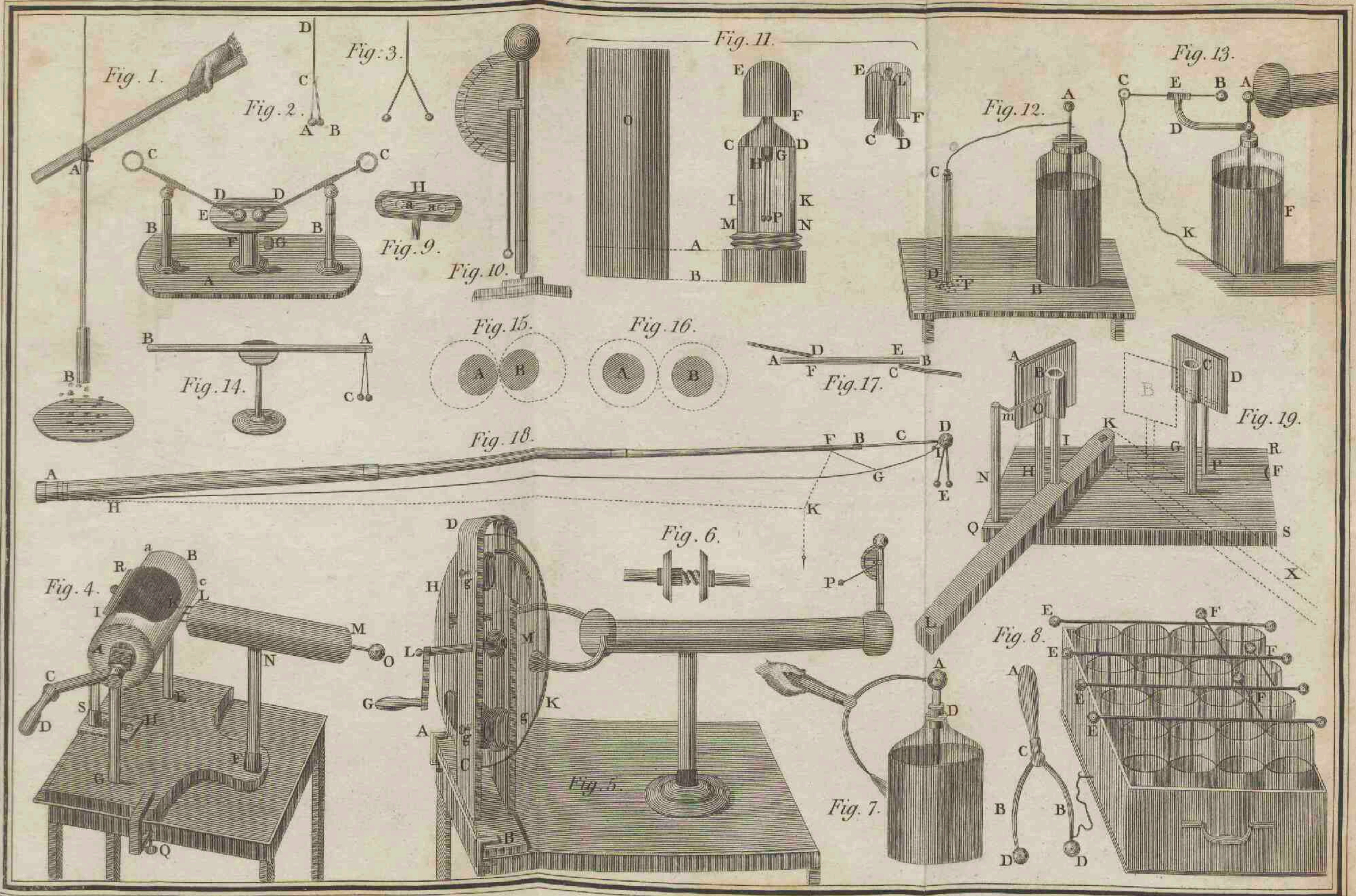

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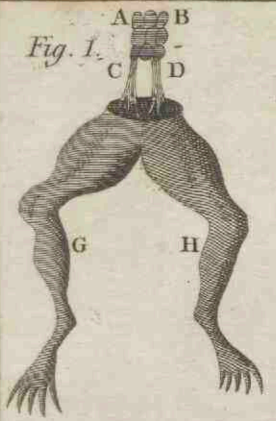
Fig. 1.


Fig. 2.


Fig. 3.

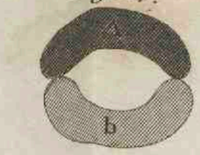
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Fig. 5.

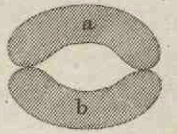


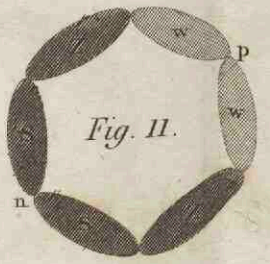
Fig. 6.


Fig. 7.


Fig. 8.


Fig. 9.


Fig. 10.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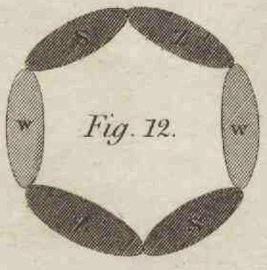
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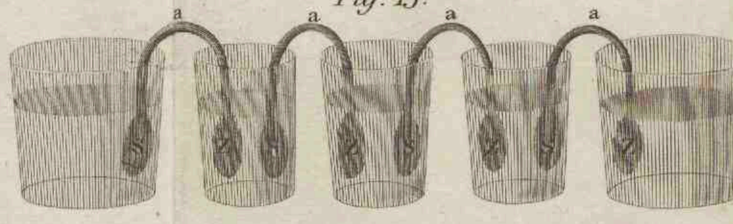
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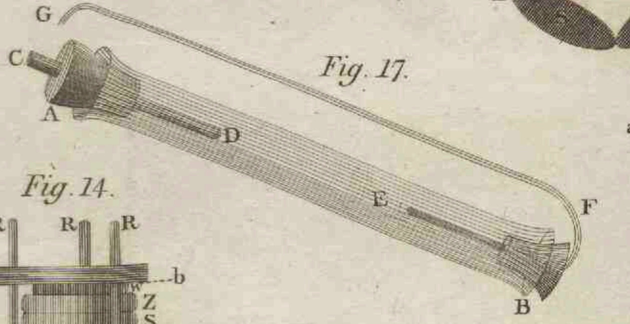
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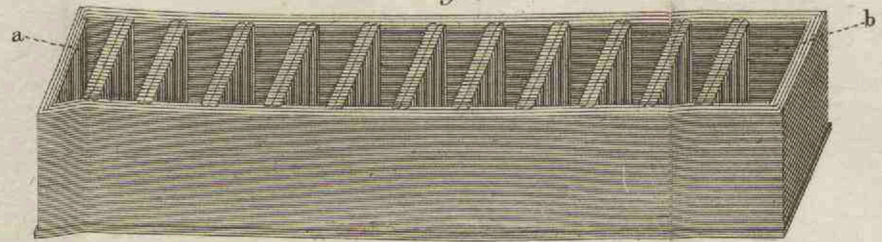
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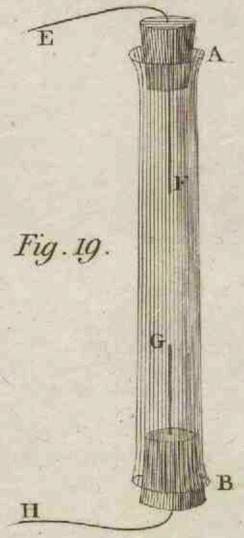
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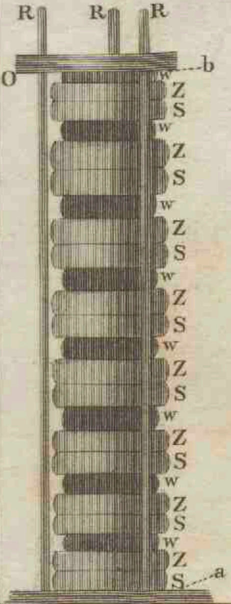
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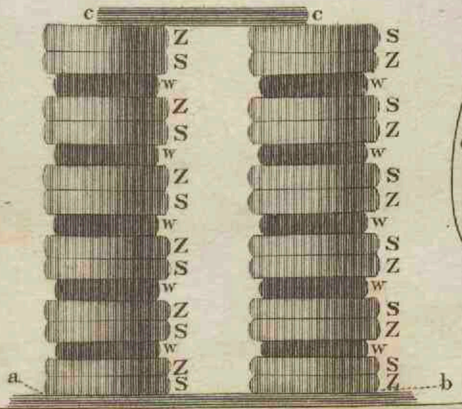
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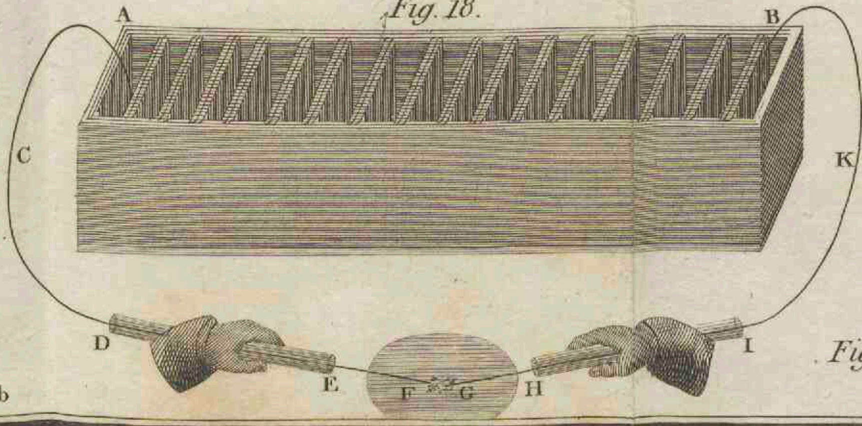
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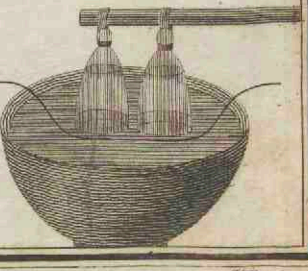
Fig. 20.

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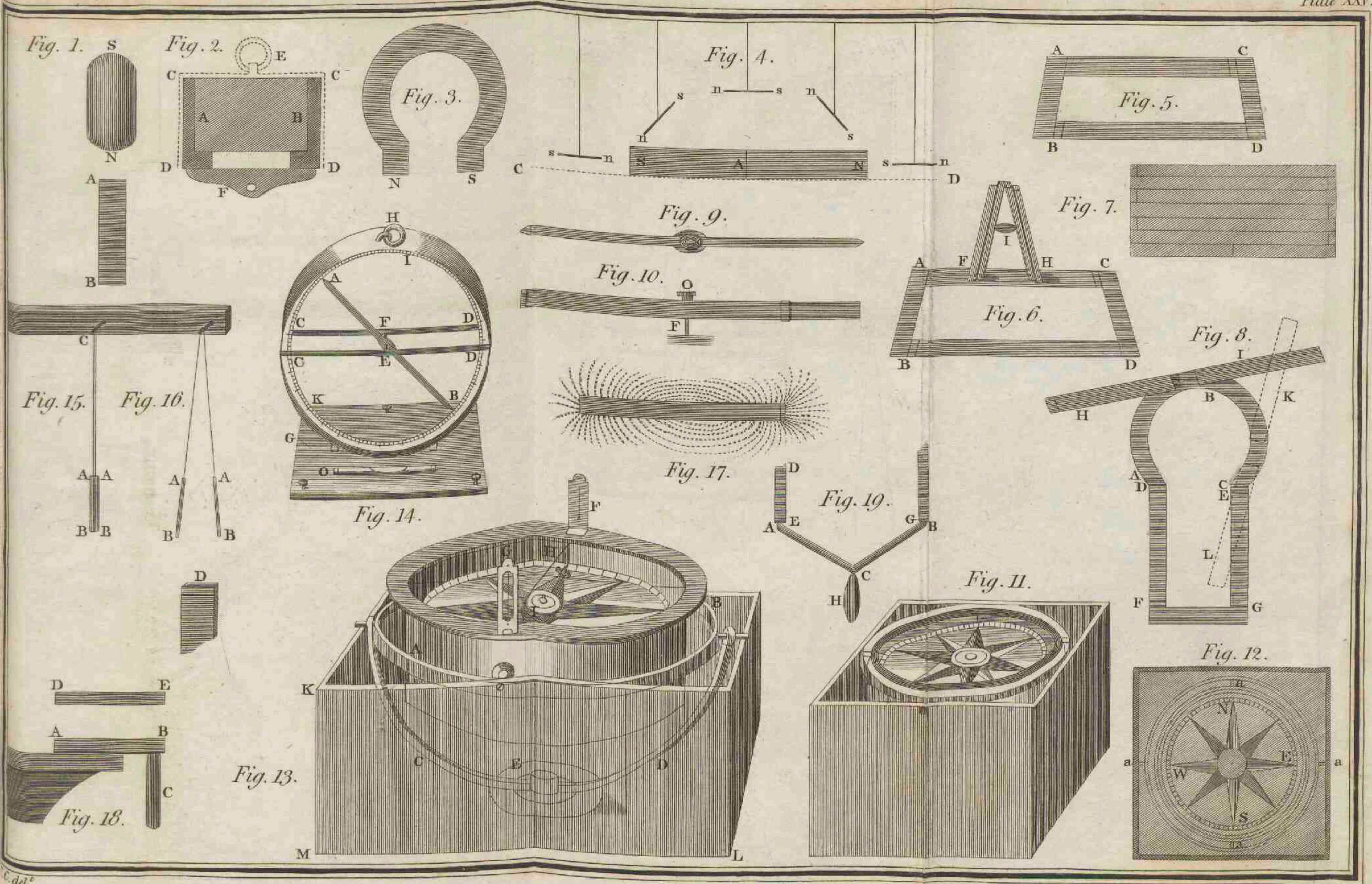
Plate XXV.



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